2018

AP CollegeBoard

AP Chemistry

Sample Student Reponses and Scoring Notes

DRAFT

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CHEMISTRY

Section II

Time—1 hour and 45 minutes

7 Questions

YOU MAY USE YOUR CALCULATOR FOR THIS SECTION.

Directions: Questions 1–3 are long free-response questions that require about 23 minutes each to answer and are worth 10 points each. Questions 4–7 are short free-response questions that require about 9 minutes each to answer and are worth 4 points each.

Write your response in the space provided following each question. Examples and equations may be included in your responses where appropriate. For calculations, clearly show the method used and the steps involved in arriving at your answers. You must show your work to receive credit for your answer. Pay attention to significant figures.

$$Na_2S_2O_3(aq) + 4\ NaOCl(aq) + 2\ NaOH(aq) \rightarrow 2\ Na_2SO_4(aq) + 4\ NaCl(aq) + H_2O(l)$$

1. A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

   (a) Determine the oxidation number of Cl in NaOCl.

   (b) Calculate the number of grams of $Na_2S_2O_3$ needed to prepare 100.00 mL of 0.500 M $Na_2S_2O_3(aq)$.

   In the experiment, the student uses the solutions shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	5.00
$NaOCl(aq)$	0.500	5.00
$NaOH(aq)$	0.500	5.00

   (c) Using the balanced equation for the oxidation-reduction reaction and the information in the table above, determine which reactant is the limiting reactant. Justify your answer.

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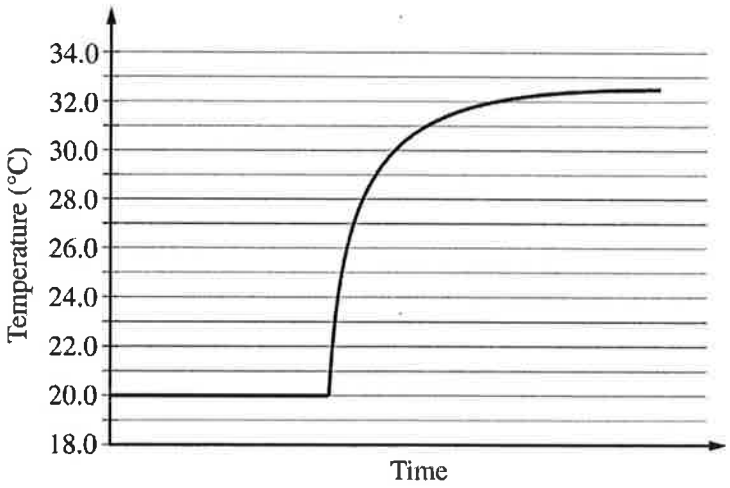
The solutions, all originally at 20.0°C, are combined in an insulated calorimeter. The temperature of the reaction mixture is monitored, as shown in the graph below.



(d) According to the graph, what is the temperature change of the reaction mixture?

(e) The mass of the reaction mixture inside the calorimeter is 15.21 g.

(i) Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g·°C) and that the heat absorbed by the calorimeter is negligible.

(ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction, ΔH°_{rxn}, in kJ/mol$_{rxn}$. Include the appropriate algebraic sign with your answer.

The student repeats the experiment, but this time doubling the volume of each of the reactants, as shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	10.0
NaOCl(aq)	0.500	10.0
NaOH(aq)	0.500	10.0

(f) The magnitude of the enthalpy change, ΔH°_{rxn}, in kJ/mol$_{rxn}$, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

(g) Write the balanced net ionic equation for the given reaction.

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Question 1

$$Na_2S_2O_3(aq) + 4\ NaOCl(aq) + 2\ NaOH(aq) \rightarrow 2\ Na_2SO_4(aq) + 4\ NaCl(aq) + H_2O(l)$$

A student performs an experiment to determine the value of the enthalpy change, ΔH°_{rxn}, for the oxidation-reduction reaction represented by the balanced equation above.

(a) Determine the oxidation number of Cl in NaOCl.

+1	1 point is earned for the correct answer.

(b) Calculate the number of grams of $Na_2S_2O_3$ needed to prepare 100.00 mL of 0.500 M $Na_2S_2O_3(aq)$.

$100.00\ mL \times \frac{0.500\ mol\ Na_2S_2O_3}{1000\ mL} \times \frac{158.10\ g\ Na_2S_2O_3}{1\ mol\ Na_2S_2O_3}$ $= 7.90\ g\ Na_2S_2O_3$	1 point is earned for correct number of moles of $Na_2S_2O_3$ (may be implicit). 1 point is earned for the correct calculation of mass of $Na_2S_2O_3$ consistent with the number of moles.

In the experiment, the student uses the solutions shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	5.00
$NaOCl(aq)$	0.500	5.00
$NaOH(aq)$	0.500	5.00

(c) Using the balanced equation for the oxidation-reduction reaction and the information in the table above, determine which reactant is the limiting reactant. Justify your answer.

NaOCl is the limiting reactant. Given that equal numbers of moles of each reactant were present initially, it follows from the coefficients of the reactants in the balanced equation that NaOCl will be depleted first.	1 point is earned for identifying the limiting reactant and providing a valid justification.

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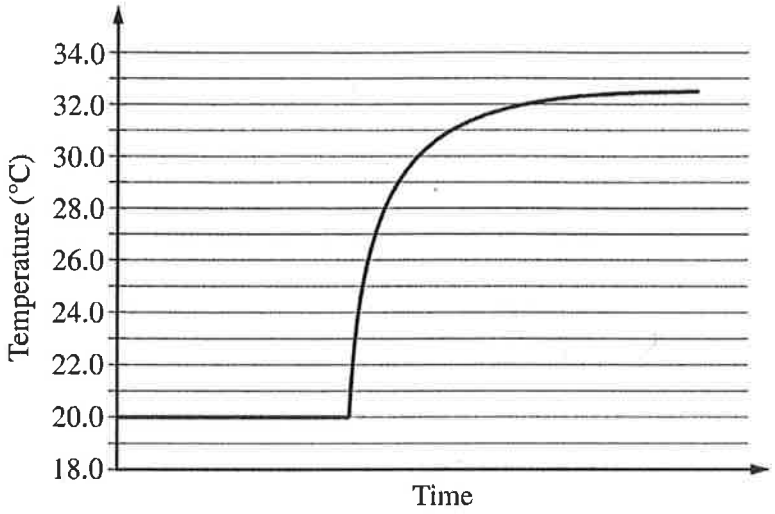
Question 1 (continued)

The solutions, all originally at 20.0°C, are combined in an insulated calorimeter. The temperature of the reaction mixture is monitored, as shown in the graph below.



(d) According to the graph, what is the temperature change of the reaction mixture?

From the graph the final temperature is 32.5°C. $\Delta T = T_f - T_i = 32.5°C - 20.0°C = 12.5°C$	1 point is earned for the correct value of ΔT.

(e) The mass of the reaction mixture inside the calorimeter is 15.21 g.

(i) Calculate the magnitude of the heat energy, in joules, that is released during the reaction. Assume that the specific heat of the reaction mixture is 3.94 J/(g·°C) and that the heat absorbed by the calorimeter is negligible.

$q = mc\Delta T$ $= (15.21\ g)(3.94\ J/(g·°C))(12.5°C) = 749\ J$	1 point is earned for the correct calculation of q consistent with the ΔT value from part (d).

(ii) Using the balanced equation for the oxidation-reduction reaction and your answer to part (c), calculate the value of the enthalpy change of the reaction, ΔH°_{rxn}, in kJ/mol_{rxn}. Include the appropriate algebraic sign with your answer.

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Question 1 (continued)

$n_{NaOCl} = 5.00\ mL \times \frac{0.500\ mol\ NaOCl}{1000\ mL\ NaOCl} = 0.00250\ mol\ NaOCl$ $n_{rxn} = 0.00250\ mol\ NaOCl \times \frac{1\ mol_{rxn}}{4\ mol\ NaOCl} = 0.000625\ mol_{rxn}$ $\Delta H^\circ_{rxn} = \frac{-0.749\ kJ}{0.000625\ mol_{rxn}} = -1.20 \times 10^3\ kJ/mol_{rxn}$	1 point is earned for correctly calculating the value of mol_{rxn} consistent with the limiting reactant in part (c). 1 point is earned for a negative ΔH°_{rxn} obtained by dividing the calculated value of q by the calculated value of mol_{rxn}.

The student repeats the experiment, but this time doubling the volume of each of the reactants, as shown in the table below.

Solution	Concentration (M)	Volume (mL)
$Na_2S_2O_3(aq)$	0.500	10.0
$NaOCl(aq)$	0.500	10.0
$NaOH(aq)$	0.500	10.0

(f) The magnitude of the enthalpy change, ΔH°_{rxn}, in kJ/mol_{rxn}, calculated from the results of the second experiment is the same as the result calculated in part (e)(ii). Explain this result.

By doubling the volumes, the number of moles of the reactants are doubled, which doubles the amount of energy produced. Therefore, the amount of heat per mole will remain the same. OR In the second experiment, $\Delta H^\circ_{rxn} = \frac{2mc\Delta T}{2n} = \frac{mc\Delta T}{n} = \Delta H^\circ_{rxn}$. Thus the magnitude is the same as calculated in the first experiment.	1 point is earned for a valid explanation.

(g) Write the balanced net ionic equation for the given reaction.

$S_2O_3^{2-}(aq) + 4\ OCl^-(aq) + 2\ OH^-(aq) \rightarrow 2\ SO_4^{2-}(aq) + 4\ Cl^-(aq) + H_2O(l)$	1 point is earned for the correct net ionic equation.

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(a) +1

(b) $\frac{0.500\ \text{mol}}{\text{L}} \times 0.10000\ \text{L} \times \frac{158.1\ \text{g}\ Na_2S_2O_3}{\text{mol}} = 7.91\ \text{g}\ Na_2S_2O_3$

(c) $\frac{0.500\ \text{mol}\ Na_2S_2O_3}{\text{L}} \times 0.00500\ \text{L} \times \frac{1\ \text{mol}\ H_2O}{1\ \text{mol}\ Na_2S_2O_3} = 0.00250\ \text{mol}\ H_2O$

$\frac{0.500\ \text{mol NaOCl}}{\text{L}} \times 0.00500\ \text{L} \times \frac{1\ \text{mol}\ H_2O}{4\ \text{mol NaOCl}} = 6.25 \times 10^{-4}\ \text{mol}\ H_2O$

$\frac{0.500\ \text{mol NaOH}}{\text{L}} \times 0.00500\ \text{L} \times \frac{1\ \text{mol}\ H_2O}{2\ \text{mol NaOH}} = 0.00125\ \text{mol}\ H_2O$

NaOCl is the limiting reactant

(d) $\Delta T = 32.5 - 20.0 = 12.5\ ^\circ C$

(e)

(i) $Q = mC\Delta T = (15.21)(3.94)(12.5) = 749\ J$

(ii) $-749\ \text{J} \times \frac{1\ \text{kJ}}{1000\ \text{J}} \times \frac{1}{6.25 \times 10^{-4}\ \text{mol rxn}} = -1.20 \times 10^{3}\ \frac{\text{kJ}}{\text{mol rxn}}$

(f) The kJ produced by this reaction will be 2x greater than that in part e but kJ/mol rxn will be the same bc there are also 2x more mols of reactants in this experiment.

(g) ~~$2\ Na^+ + S_2O_3^{2-} + 4\ Na^+ + 4\ OCl^- + 2\ Na^+ + 2\ OH^- \rightarrow 4\ Na^+ + 2\ SO_4^- + 4\ Na^+ + 4\ Cl^- + H_2O$~~

$S_2O_3^{2-}(aq) + 4\ OCl^-(aq) + 2\ OH^-(aq) \rightarrow 2\ SO_4^{2-}(aq) + 4\ Cl^-(aq) + H_2O(l)$

PAGE FOR ANSWERING QUESTION 1

a) NaOCl Na: +1 O: -2 $0 = 1 - 2 + x$

$x = 1$ Cl: $\boxed{+1}$

b) $M = mol/L$

$mol = M(L)$

$mol = 0.500\,M\,(100.0\,mL)\left(\frac{1\,L}{1000\,mL}\right)$

$mol = 0.0500$

$0.0500\,mol\,Na_2S_2O_3\left(\frac{2(22.99)+2(32.06)+3(16.00)\,g}{1\,mol\,Na_2S_2O_3}\right)$

$= 0.0500\,mol\,Na_2S_2O_3\left(\frac{158.10\,g}{1\,mol\,Na_2S_2O_3}\right)$

$= \boxed{7.90\,g\,Na_2S_2O_3}$

c) $mol = M(L)$

$mol = 0.500M\,(5.00\,mL)\left(\frac{1\,L}{1000\,mL}\right)$

$mol = 0.00250$

There are 0.00250 mol of each reactant. Based on the reaction equation, the reactants have a ratio of $\frac{4\,mol\,NaOCl}{1\,mol\,Na_2S_2O_3}$ and $\frac{2\,mol\,NaOCl}{1\,mol\,NaOH}$.

This means there's an excess of NaS_2O_3 and NaOH. NaOCl is the limiting reagent.

d) $\Delta T = T_f - T_i$

$= 32.5°C - 20.0°C$

$= \boxed{12.5°C}$

e) i) $q = mc\Delta T$

$q = 15.21\,g\,(3.94\,J/g·°C)(12.5°C)$

$q = 749.0925\,J$

3 s.f. = $\boxed{749\,J}$

e) ii)

$$\frac{4\ \text{mol NaOCl}}{1\ \text{mol rxn}}\left(\frac{1}{0.00250\ \text{mol NaOCl}}\right) = 1.60\times10^{3}\ \text{mol rxn}$$

$$\frac{1.60\times10^{3}}{\text{mol rxn}}(749\ \text{J}) = 1198400\ \text{J/mol rxn}$$

$$1198400\ \text{J/mol rxn}\left(\frac{1\ \text{kJ}}{1000\ \text{J}}\right) = 1198.4\ \text{kJ/mol rxn}$$

$$3\ \text{s.f.} = 1.20\times10^{3}\ \text{kJ/mol rxn}$$

$$\text{exothermic} = \boxed{-1.20\times10^{3}\ \text{kJ/mol rxn}}$$

f) ΔH°_{rxn} is standard enthalpy change for 1 mol of the reaction at 298K and 1.00atm. It does not change unless temperature or pressure changes.

g) $S_2O_3^{2-}(aq) + 4\,OCl^{-}(aq) + 2OH^{-}(aq) \rightarrow 2SO_4^{2-}(aq) + 4\,Cl^{-}(aq) + H_2O(l)$

PAGE FOR ANSWERING QUESTION 1

1a) $\overset{1+}{Na}OCl$ $\quad OCl \rightarrow -1$ (total) $\quad \overset{2-}{O}\overset{1+}{Cl}$

oxidation # for Cl = 1+

1b) $M_{Na_2S_2O_3} = (22.99 \times 2) + (32.06 \times 2) + (16.00 \times 3) = 158.1\ g/mol$

$m_{Na_2SO_3} = Mn$

$n = [Na_2SO_3]V$

$m_{Na_2S_2O_3} = M[Na_2SO_3]V = \left(\frac{158.1\ g}{mol}\right)\left(\frac{0.500\ mol}{L}\right)(100.00 \times 10^{-3}\ L)$

$m = 7.905\ g \rightarrow$ **7.91 g**

1c) **NaOCl**

- $n = [solution]V$
  - all solutions have same molarity & volume → same # of mol
- 4 mol of NaOCl is required for every 2 mol of NaOH & 1 mol of $Na_2S_2O_3$

→ NaOCl will run out before anything else runs out

1d) $\Delta T = T_f - T_i = 32.5°C - 20.0°C =$ **12.5°C**

1e) i) $q = mc\Delta T = (15.21\ g)\left(\frac{3.94\ J}{g \cdot °C}\right)(12.5°C) = 749.0925\ J$

→ **749 J is released**

1e) ii) $\Delta H = -749\ J$

$\Delta H°_{rxn} = \frac{\Delta H}{n_{Na_2SO_4}}$

NaOCl is limiting reagent.

4 mol NaOCl ≙ 2 mol Na_2SO_4

$n_{Na_2SO_4} = (n_{NaOCl})\left(\frac{2}{4}\right) = [NaOCl](V_{NaOCl})(0.5) = \left(\frac{0.500\,mol}{L}\right)(5.00\times10^{-3}\,L)(0.5)$

$n_{Na_2SO_4} = 0.00125\,mol$

$\Delta H°_{rxn} = \frac{\Delta H}{n_{Na_2SO_4}} = \frac{-749\times10^{-3}\,kJ}{0.00125\,mol} = 599.2\,kJ/mol \rightarrow \boxed{599\,kJ/mol}$

1f) - $\Delta H°_{rxn}$ is a value of heat absorbed / released per 1 mol of rxn

$\Rightarrow \Delta H°_{rxn} = \frac{\Delta H}{n}$

- if n doubles, ΔH also doubles since ΔH is directly proportional to the amount of reactants available
- if both top & bottom of fraction is multiplied by 2, there is no change to value of $\Delta H°_{rxn}$

g) $S_2O_3^{2-}(aq) + 4OCl^-(aq) + 2OH^-(aq) \rightarrow 2SO_4^{2-}(aq) + 4Cl^-(aq) + H_2O(\ell)$

PAGE FOR ANSWERING QUESTION 1

ID 1 of 2

a) #1 Cl

b) $\frac{100\,mL}{1}\left(\frac{0.5\,mol}{1000\,mL}\right)\left(\frac{158.1\,g}{1\,mol}\right) = 7.905$ **7.91 g $Na_2S_2O_3$**

c) $\frac{5\,mL\ Na_2S_2O_3}{1}\left(\frac{0.5\,mol}{1000\,mL}\right)\left(\frac{2\,mol\ Na_2SO_4}{1\,mol\ Na_2S_2O_3}\right) = 0.005\ mol$

$\frac{5\,mL\ NaOCl}{1}\left(\frac{0.5\,mol}{1000\,mL}\right)\left(\frac{2\,mol\ Na_2SO_4}{4\,mol\ NaOCl}\right) = 0.00125\,mol$

$\frac{5\,mL}{1}\left(\frac{0.5\,mol\ NaOH}{1000\,mL}\right)\left(\frac{2\,mol\ Na_2SO_4}{2\,mol\ NaOH}\right) = 0.0025$

The NaOCl is the limiting reactant

d) $32.5 - 20 = \boxed{12.5\,^\circ C}$

e) i) $q = mc\Delta T \quad q = (15.2\,g)\left(3.94\frac{J}{g\,^\circ C}\right)(12.5\,^\circ C)$

$q = 749.025 \quad \boxed{749\,J}$

ii) $\frac{749\,J}{1}\left(\frac{1\,kJ}{1000\,J}\right) = \frac{0.749\,kJ}{0.00125\,mol} = \boxed{-599\,kJ/mol}$

f) doubling the reactants will also double the amount of products created, thus keeping the ratio and the kJ per mol the same

g) $2OH^-_{(aq)} \rightarrow H_2O_{(l)}$

PAGE FOR ANSWERING QUESTION 1

1a. +1

b. $\frac{100mL}{1}\left(\frac{.5mol}{1000mL}\right)\left(\frac{158g}{1mol}\right) = 7.91\ g\ of\ Na_2S_2O_3$

c. $\frac{5mL}{1}\left(\frac{.5mol}{1000mL}\right) = .0025mol\ Na_2S_2O_3$ coeff = 1

$\frac{5mL}{1}\left(\frac{.5mol}{1000mL}\right) = .0025mol\ NaOCl$ coeff = 4

$\frac{5mL}{1}\left(\frac{.5mol}{1000mL}\right) = .0025mol\ NaOH$ coeff = 2

NaOCl is the limiting reactant because all the reactants in the experiments have the same number of moles and with the coeff on NaOCl being four, this means the reaction needs the most of it making it run out first

d. $32.5 - 20.0 = 12.5°C$

e.i. $q = (15.21g)(3.94\ 31\ J/g \cdot °C)(12.5°C)$

$q = 749J$ is released

ii. $-.749KJ/mol$

f. the only difference with this equation is that all the volumes are double which doesn't change the ΔH°_{rxn} because the change is universal among all the reactants.

g. $S_2O_3^{2-}{}_{(aq)} + 4OCl^{1-}{}_{(aq)} + 2OH^-{}_{(aq)} \rightarrow 2SO_4^{2-}{}_{(aq)} + Cl^-{}_{(aq)} + H_2O_{(l)}$

PAGE FOR ANSWERING QUESTION 1

1F 1 of 2

a. $\overset{+3}{Na}\overset{-2}{O}\overset{-1}{Cl}$

Oxidation number for Cl is -1

b. $Mol = \frac{m}{L}$ $\quad 0.500\,M = \frac{X}{160\,mL \cdot \frac{1L}{1000\,mL}}$

$.05\ mol\ Na_2S_2O_3 \cdot \frac{158\ g}{1\ mol} = 7.90\ g\ Na_2S_2O_3$

$2(23) + 2(32) + 3(16) = 158$

c. $Na_2S_2O_3 + 4NaOCl + 2NaOH \rightarrow 2Na_2SO_4 + 4NaCl + H_2O$

$0.500\,M\ Na_2S_2O_3 \cdot 0.005\,mL = 0.0025\ mol\ Na_2S_2O_3$

$0.500\,M\ NaOCl \cdot 0.005\,mL = 0.0025\ mol\ NaOCl$

$0.500\,M\ NaOH \cdot 0.005\,mL = 0.0025\ mol\ NaOH$

$\frac{.0025\ mol\ Na_2S_2O_3}{1} \cdot \frac{2\ mol\ Na_2SO_4}{1\ mol\ Na_2S_2O_3} = 0.005\ mol\ Na_2SO_4$

$\frac{.0025\ mol\ NaOCl}{1} \cdot \frac{2\ Na_2SO_4}{4\ mol\ NaOCl} = 0.00125\ mol\ Na_2SO_4$

$\frac{.0025\ mol\ NaOH}{1} \cdot \frac{2\ mol\ Na_2SO_4}{2\ mol\ NaOH} = 0.0025\ mol\ Na_2SO_4$

NaOCl is the limiting reactant because it would produce the smallest amount of Na_2SO_4 out of the 3 reactants

GO ON TO THE NEXT PAGE.

d. $\Delta T = T_F - T_i$

$\Delta T = 32.5°C - 20.0°C$

$\Delta T = 12.5°C$

Temperature change is 12.5°C

e. i $q = mc\Delta T$ $q = (15.21g)(3.94\ J/g°C)(12.5°C)$

$q = 749\ J$

i: $\frac{749\ J}{1} \cdot \frac{1\ kJ}{1000\ J} = 0.749\ kJ$

$\frac{0.0025\ mol\ NaOH}{1} \cdot \frac{0.749\ kJ}{2\ mol\ NaOH} = 9.4 \cdot 10^{-4}$

$\Delta H° = 9.4 \cdot 10^{-4}\ kJ/mol\ rxn$

f. This happens because the same ratio of heat to moles is being used.

g. $H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$

1a) The oxidation number of Cl in NaOCl is -1

b) $M = \frac{\text{moles}}{L}$ $\quad .5 = \frac{\text{moles}}{.1}$ $\quad .05 \text{ mole} \left| \frac{158.1 \text{ g}}{1 \text{ mole}} \right.$ $\quad$ **7.91 grams $Na_2S_2O_3$**

c) NaOCl is the limiting reactant because all of the species have the same amount of moles ($.005L \times .5M = .0025$ moles) but NaOCl has a coefficient of 4, meaning 4 times as much is used than $Na_2S_2O_3$ & 2 times as much is used than NaOH.

d) $\Delta T = 32.5^\circ C - 22.0^\circ C =$ **$10.5^\circ C$**

e i) $q = mc\Delta T = (15.21)(3.94)(10.5) =$ **629.2 J**

ii) $\Delta H = -q_{rxn}$ $\quad q = (.682)(3.94)(10.5) =$ **-2.8×10^{-3} KJ/mol**

f) These results occur because they are calculations of KJ/mol, & it remains the same molar ratio, therefore the value will be the same.

g) $2Na^+ + 2S^{+2} + 3O^{-2}$

a) NaOCl

Na^{+1} $\quad$ $Na^{+1}O^{-}$

O^{-2} $\quad$ $NaXO$

$Cl^{?}$ $\quad$ $Na_2O^{-1} + Cl$

Oxidation number -1

b) $M = \frac{mol}{L}$ $\quad$ 100 mL => .1 L

$.5\,M = \frac{mol}{.1} = .05\,mol$

mm = 158.1 $\quad$ $\frac{.05\,mol}{1} \mid \frac{158.1}{1\,mol} = 7.91\,g\,Na_2S_2O_3$

c) NaOCl is the limiting reactant because the reaction requires the most moles of ~~this~~ reactant to follow through.

d) The change in temperature is approximately 12.5°C.

ei) $q = m c \Delta t$ $\quad$ $12.5 + 273 = 285.5$

$q = (15.21)(3.94)(285.5)$

$q = 17109.2727$

$q = 17100$ joules

eii) $\Delta H = \sum p_{rod} - \sum r_{eact}$

$\Delta H_{rxn} = [(2 \cdot x) + (4 \cdot y)] - [(a) + (4 \cdot b) + 2 \cdot c]$

$\Delta H_{rxn} = (2(.5) + 4(.5)) - (.5 + 4(.5) + 2(.5))$

$\Delta H = -.5$ kJ/mol rxn

f) The magnitude of the enthalpy change stays the same because the concentrations of the reactants and products remain the same values, and a change in volume doesn't affect enthalpy.

g) $4NaOCl \rightarrow 4NaCl + H_2O$

$Na_2S_2O_3 + 2NaOH \rightarrow 2Na_2SO_4 + H_2O$

$H_2O + 2Na_2SO_4 \rightarrow Na_2S_2O_3 + 2NaOH$

$4NaOCl + 2Na_2SO_4 \rightarrow Na_2S_2O_3 + 2NaOH$

(a) I^-

(b) $100.0\,mL = 1.0\,L$ $\quad .500\,M\,Na_2S_2O_3(aq) = \frac{x\,mol}{1.0\,L} = .500\,mol\,Na_2S_2O_3$

$.500\,mol\,Na_2S_2O_3 \mid 158.1\,g\,Na_2S_2O_3 = 79.05\,g\,Na_2S_2O_3$ needed
$\quad\quad\quad

PAGE FOR ANSWERING QUESTION 1

1A) The oxidation number for Cl in NaOCl is zero.

B) $.500M\ Na_2S_2O_3 = \frac{X\ grams}{.100L}$ 5 grams of $Na_2S_2O_3$ are needed, as shown in the math on the left.

C)

R	$Na_2S_2O_3$	+ 4 NaOCl	+ 2NaOH	→ $2Na_2SO_4$	+ 4NaCl	+ H_2O
I	1 (.500 M)	4 (.500M)	2 (.500M)	Ø	Ø	Ø
C	-.500	-.500	-.500	+.500	+.500	+.500
E	Ø	1.50M	.500M	.500M	.500M	.500M

$Na_2S_2O_3$ is the limiting reactant, as shown in the rice chart above. Because the coefficient on $Na_2S_2O_3$ is a one and this is not an equilibrium reaction, $Na_2S_2O_3$ will be used completely, and is therefore the limiting reactant.

D) 32.5
-20.0
12.5 = approx. temperature change

Ei) $3.94\ J/(g \cdot C^\circ) = \frac{X}{(15.21 \times 12.5)}$ X = -0207 J of heat energy released during the reaction.

1J 2 of 2

Eii) $\Delta H = \Sigma$ Products $- \Sigma$ reactants

$\Delta H = [(2 \times 500) + (4 \times .500) + (.500)] - [(4 \times 1.50) + (2 \times .500)]$

$\Delta H = -3.50$ KJ/molan

F) Although the volume changes, the molarity of all the substances does not. Because molarity is what's plugged into the RICE Chart and its values are used in Eii, the magnitude of the enthalpy value will not change.

G) ~~$Na_2S_2O_3 + NaOCl + 2NaOH \rightarrow SO_4^{-2}$~~

$Na_2S_2O_3 + NaOCl \rightarrow SO_4^{-2} + Na^{+1} + Cl^{-1}$

AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
2018 AP CHEMISTRY

Question 1

Sample Identifier: 1A
Score: 10

- a) 1 point was earned for the correct oxidation number.
- b) 2 points were earned. The first point was earned for showing the calculation for moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$ (7.91 g is acceptable according to rounding conventions)
- c) 1 point was earned for identifying NaOCl as the limiting reactant and justifying the answer by showing that NaOCl would produce the least moles of H_2O.
- d) 1 point was earned for the correct value for ΔT.
- e-i) 1 point was earned for the correct calculation of q using the ΔT from part (d).
- e-ii) 2 points were earned. One point was earned for the correct determination of the moles of reaction. The second point was earned for dividing the calculated q from part (e-i) by the moles of reaction and making it negative.
- f) 1 point was earned for correctly explaining that both the heat produced by the reaction and the number of moles would double leading to the same kJ/mol_{rxn}.
- g) 1 point was earned for the correct net ionic equation.

Sample Identifier: 1B
Score: 9

- a) 1 point was earned for the correct oxidation number.
- b) 2 points were earned. The first point was earned for correctly calculating the moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$.
- c) 1 point was earned for identifying NaOCl as the limiting reactant and correctly explaining that because there were 0.00250 moles of each reactant, the mole ratios from the balanced equation would lead to an excess of $Na_2S_2O_3$ and NaOH.
- d) 1 point was earned for the correct value for ΔT.
- e-i) 1 point was earned for the correct calculation of q using the ΔT from part (d).
- e-ii) 2 points were earned. One point was earned for the correct determination of $1/mol_{rxn}$. The second point was earned for correctly using the calculated value and multiplying by q to get the correct, negative ΔH_{rxn}.
- f) The point was not earned. The explanation that the standard enthalpy change is only affected by temperature and pressure was not sufficient. The response did not indicate that the increase in moles would lead to a corresponding increase in heat produced using experimental details.
- g) 1 point was earned for the correct net ionic equation.

Sample Identifier: 1C
Score: 8

- a) 1 point was earned for the correct oxidation number.
- b) 2 points were earned. The first point was earned for showing the calculation for moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$.
- c) 1 point was earned for identifying NaOCl as the limiting reactant and correctly explaining that because there were equal moles of each reactant, the mole ratios from the balanced equation would cause NaOCl to run out first.
- d) 1 point was earned for the correct value for ΔT.
- e-i) 1 point was earned for the correct calculation of q using the ΔT from part (d).
- e-ii) The two points were not earned. The first point was not earned due to an incorrect calculation of mol_{rxn}. The second point was not earned. Although the student correctly divided a negative calculated q from part (e-i) by the calculated moles of reaction, a positive ΔH_{rxn} was reported.

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- f) 1 point was earned for the correct explanation that when moles are doubled, ΔH is also doubled, which would leave ΔH_{rxn} unchanged.
- g) 1 point was earned for the correct net ionic equation.

Sample Identifier: 1D
Score: 7

- a) 1 point was earned for the correct oxidation number.
- b) 2 points were earned. The first point was earned for showing the calculation for moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$.
- c) 1 point was earned for identifying NaOCl as the limiting reactant and correctly calculating that NaOCl would produce the least moles of Na_2SO_4.
- d) 1 point was earned for the correct value for ΔT.
- e-i) 1 point was earned for the correct calculation of q using the ΔT from part (d).
- e-ii) 1 of 2 points was earned. The first point was not earned due to an incorrect calculation of mol_{rxn}. The second point was earned for dividing the calculated q from part (e-i) by the calculated moles of reaction and making it negative.
- f) The point was not earned. The response indicated that doubling the amount of reagents would double the amount of products, but did not make reference to the effect on the heat produced.
- g) The point was not earned. The equation was incorrect.

Sample Identifier: 1E
Score: 6

- a) 1 point was earned for the correct oxidation number.
- b) 2 points were earned. The first point was earned for showing the calculation for moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$.
- c) 1 point was earned for identifying NaOCl as the limiting reactant and correctly explaining that because there were equal moles of each reactant, the mole ratios from the balanced equation would cause NaOCl to run out first.
- d) 1 point was earned for the correct value for ΔT.
- e-i) 1 point was earned for the correct calculation of q using the ΔT from part (d).
- e-ii) The two points were not earned. The first point was not earned. The student did not calculate mol_{rxn}. The second point was not earned. The answer involved only a conversion from J to kJ.
- f) The point was not earned. The student indicated only that ΔH_{rxn} did not rely on volumes and did not reference the effect of doubling the volume on the number of moles and the heat produced.
- g) The point was not earned. The equation was not balanced, it is missing the coefficient 4 for Cl^-.

Sample Identifier: 1F
Score: 5

- a) The point was not earned. The oxidation number on chlorine was reported as -1.
- b) 2 points were earned. The first point was earned for correctly calculating the moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$.
- c) 1 point was earned for identifying NaOCl as the limiting reactant and justifying the answer by showing that NaOCl would produce the least moles of Na_2SO_4.
- d) 1 point was earned for the correct value for ΔT.
- e-i) 1 point was earned for the correct calculation of q using the ΔT from part (d).
- e-ii) The two points were not earned. The first point was not earned. The student did not calculate mol_{rxn} consistent with the limiting reactant identified in part (c). The second point was not earned. The student multiplied q by the mol_{rxn} instead of dividing and did not make it negative.
- f) The point was not earned. The response compared the ratio of heat to moles, but did not sufficiently apply this statement to the experiment.
- g) The point was not earned. The equation was incorrect.

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AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
2018 AP CHEMISTRY

Sample Identifier: 1G
Score: 4

- a) The point was not earned. The oxidation number on chlorine was reported as -1.
- b) 2 points were earned. The first point was earned for correctly calculating the moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$.
- c) 1 point was earned for identifying NaOCl as the limiting reactant and correctly explaining that because there were equal moles of each reactant, the mole ratios from the balanced equation would require 4 times as much NaOCl as $Na_2S_2O_3$ and twice as much as NaOH.
- d) The point was not earned for the incorrect value for ΔT.
- e-i) 1 point was earned for the correct calculation of q using the ΔT from part (d).
- e-ii) The two points were not earned. The first point was not earned. The student did not calculate mol_{rxn}. The second point was not earned. The student solved for q again with a different mass and incorrectly indicated that "$\Delta H = -q_{rxn}$".
- f) The point was not earned. The response indicates the same molar ratios, but does not reference the heat produced.
- g) The point was not earned. The equation was incorrect.

Sample Identifier: 1H
Score: 3

- a) The point was not earned. The oxidation number on chlorine was reported as -1.
- b) 2 points were earned. The first point was earned for correctly calculating the moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$.
- c) The point was not earned. Although the student identified NaOCl as the limiting reactant, the explanation failed to reference the equal moles of each reactant.
- d) 1 point was earned for the correct value for ΔT.
- e-i) The point was not earned. The student incorrectly converted the ΔT from part (d) to Kelvin by adding 273.
- e-ii) The two points were not earned. The first point was not earned. The student did not calculate mol_{rxn}. The second point was not earned. The student incorrectly attempted to solve for ΔH_{rxn} using the equation $\Delta H_{rxn} = \sum products - \sum reactants$.
- f) The point was not earned. The response incorrectly indicates that "a change in volume doesn't affect enthalpy".
- g) The point was not earned. The equation was incorrect.

Sample Identifier: 1I
Score: 2

- a) The point was not earned. The oxidation number on chlorine was reported as -1.
- b) 1 of 2 points were earned. The first point was not earned. The student used 1.0 L rather than 0.100 L in calculating the moles of $Na_2S_2O_3$. The second point was earned for the correct calculation of the mass of $Na_2S_2O_3$ consistent with the calculated number of moles.
- c) The point was not earned. The student identified the limiting reactant as $Na_2S_2O_3$.
- d) 1 point was earned for the correct value for ΔT.
- e-i) The point was not earned. The student used an incorrect equation in solving for q.
- e-ii) The two points were not earned. The first point was not earned. The student did not calculate mol_{rxn}. The second point was not earned. The student incorrectly added the calculated moles times the coefficient from the calculations in part (c). The student failed to divide q by the mol_{rxn}.
- f) The point was not earned. The response incorrectly indicates "that enthalpy is only influenced by temperature change" and does not refer to the ratio of enthalpy to moles.
- g) The point was not earned. The equation was incorrect.

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AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
2018 AP CHEMISTRY

Sample Identifier: 1J
Score: 1

- a) The point was not earned. The oxidation number on chlorine was reported as 0.
- b) The two points were not earned. The first point was not earned as the student failed to calculate moles of $Na_2S_2O_3$. The second point was not earned as the mass calculation is incorrect.
- c) The point was not earned. The student identified the limiting reactant as $Na_2S_2O_3$.
- d) 1 point was earned for the correct value for ΔT.
- e-i) The point was not earned. The student incorrectly calculates q.
- e-ii) The two points were not earned. The first point was not earned. The student did not calculate mol_{rxn}. The second point was not earned. The student incorrectly attempted to solve for ΔH_{rxn} using the equation $\Delta H_{rxn} = \sum products - \sum reactants$.
- f) The point was not earned. The response refers to volume changes, but not changes in the number of moles and fails to address changes in heat produced.
- g) The point was not earned. The equation was incorrect.

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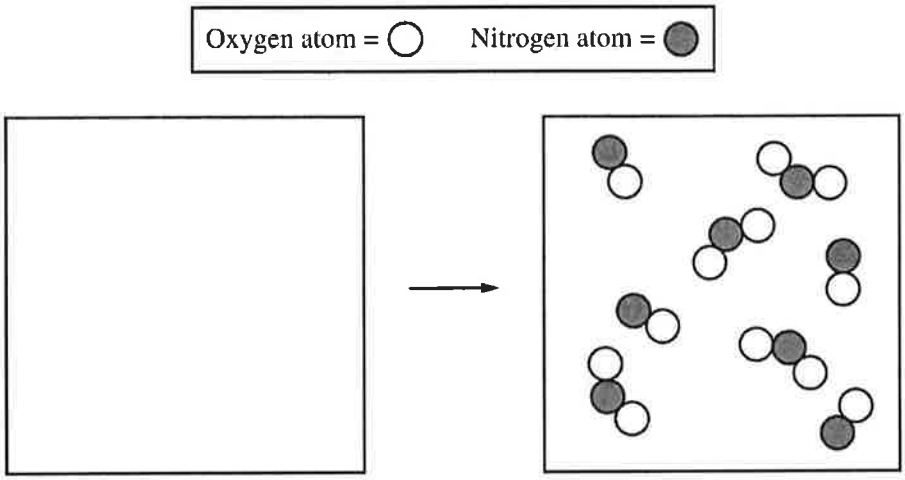
$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



Reactant Mixture Product Mixture

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ kJ/mol_{rxn}$	$-138.5\ J/(K \cdot mol_{rxn})$	$0.87\ kJ/mol_{rxn}$

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

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$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\ HNO_2(aq)$$

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

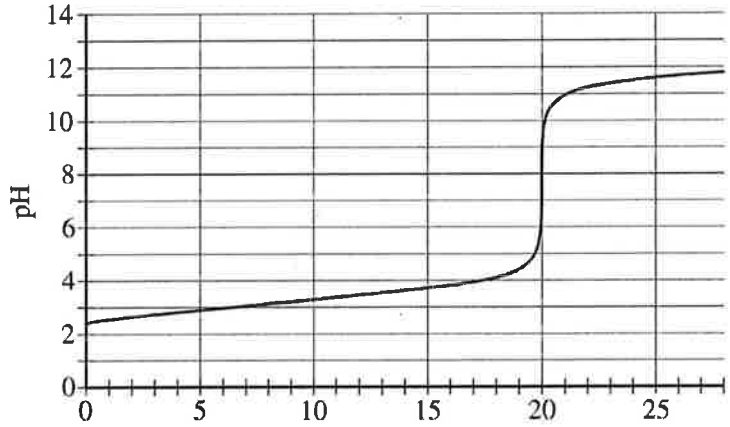
H O N O

(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

$$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

The following titration curve shows the change in pH of the solution during the titration.



(e) Use the titration curve and the information above to

(i) determine the initial concentration of the $HNO_2(aq)$ solution

(ii) estimate the value of pK_a for $HNO_2(aq)$

(f) During the titration, after a volume of 15 mL of 0.100 *M* KOH(*aq*) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

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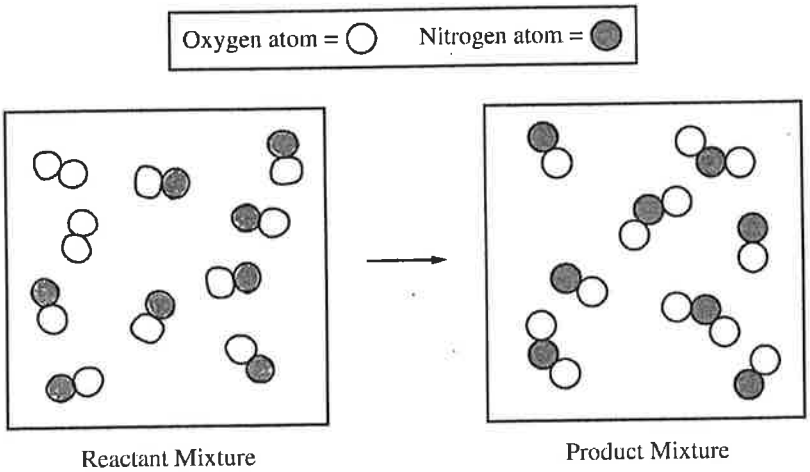
Question 2

$$2\ NO(g) + O_2(g) \rightarrow 2\ NO_2(g)$$

A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



See sample student response above. (8 molecules of NO and 2 molecules of O_2)	1 point is earned for correctly representing molecules of NO and O_2. 1 point is earned for correctly representing atom conservation.

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ kJ/mol_{rxn}$	$-138.5\ J/(K \cdot mol_{rxn})$	$0.87\ kJ/mol_{rxn}$

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Question 2 (continued)

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

$\Delta G° = -RT\ln K$ $K = e^{-\Delta G°/RT}$ $K = e^{-\frac{870\ \text{J/mol}}{(8.314\ \text{J mol}^{-1}\ \text{K}^{-1})(298\ \text{K})}}$ $K = 0.70$	1 point is earned for a correct calculation of K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

No, the pressure will not equal 1 atm. $P_{N_2O_3}$ would only equal 1 atm if the reaction goes to completion. OR The value of K indicates that a substantial amount of reactants will be present at equilibrium.	1 point is earned for a correct choice and valid justification based on the value of K.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

Disagree. Because the reaction is exothermic, increasing the temperature of the reaction will favor the formation of the reactants (according to Le Chatelier's principle).	1 point is earned for the correct choice and a correct justification.

$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\ HNO_2(aq)$$

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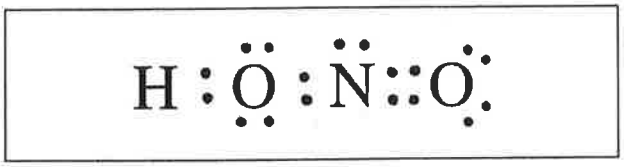
Question 2 (continued)

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.



See sample response above. (Line segments can be used to represent electron pairs.)	1 point is earned for a valid diagram.

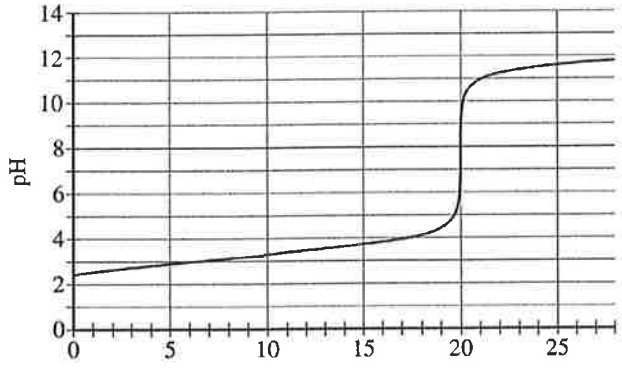
(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

sp^2	1 point is earned for the correct answer.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

$$HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$$

The following titration curve shows the change in pH of the solution during the titration.



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Question 2 (continued)

(e) Use the titration curve and the information above to

(i) determine the initial concentration of the $HNO_2(aq)$ solution

$20.\ \text{mL KOH} \times \frac{0.100\ \text{mol KOH}}{1000\ \text{mL KOH}} = 0.0020\ \text{mol KOH added}$ $\Rightarrow$ 0.0020 mol HNO_2 in 100. mL of solution because the stoichiometry of the neutralization reaction is 1 to 1. $\frac{0.0020\ \text{mol HNO}_2}{0.100\ \text{L}} = 0.020\ M\ \text{HNO}_2$	1 point is earned for the correct calculation of the initial concentration.

(ii) estimate the value of pK_a for $HNO_2(aq)$

The value of pK_a is about 3.4.	1 point is earned for an acceptable estimate for the value of pK_a.

(f) During the titration, after a volume of 15 mL of 0.100 M KOH(aq) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

$NO_2^-(aq)$ The titration is past the half-equivalence point, therefore there will be more conjugate base present than acid.	1 point is earned for the correct choice and a valid justification.

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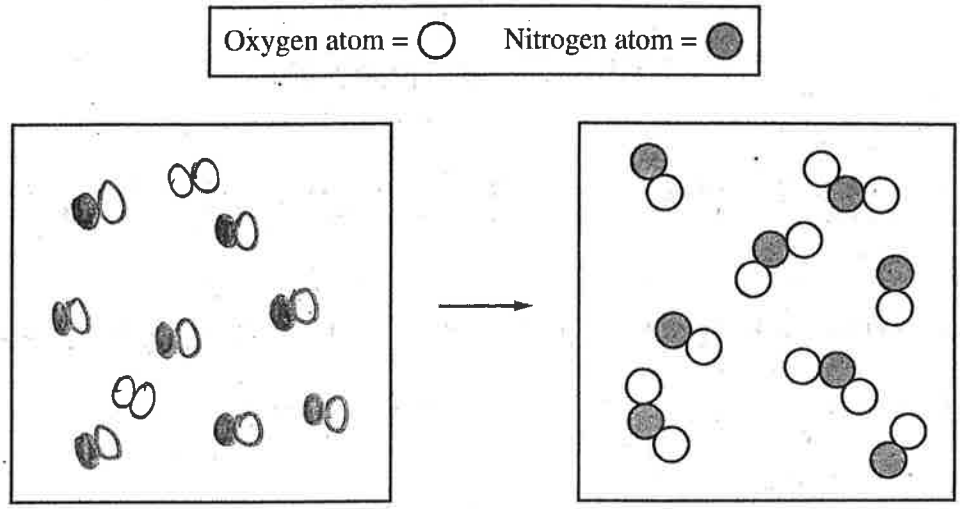
2A 1 of 3

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

(a) The particle-level representation of the equimolar mixture of $NO(g)$ and $NO_2(g)$ in the flask at the completion of the reaction between $NO(g)$ and $O_2(g)$ is shown below in the box on the right. In the box below on the left, draw the particle-level representation of the reactant mixture of $NO(g)$ and $O_2(g)$ that would yield the product mixture shown in the box on the right. In your drawing, represent oxygen atoms and nitrogen atoms as indicated below.



Reactant Mixture Product Mixture

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g) + \text{heat}$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ \text{kJ/mol}_{rxn}$	$-138.5\ \text{J/(K}\cdot\text{mol}_{rxn})$	$0.87\ \text{kJ/mol}_{rxn}$

not spontaneous

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

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2A 2 of 3

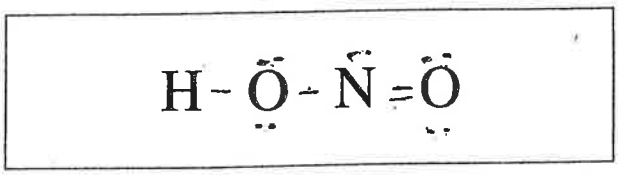
$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\ HNO_2(aq)$$

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

valence e⁻: 18
wants: 26

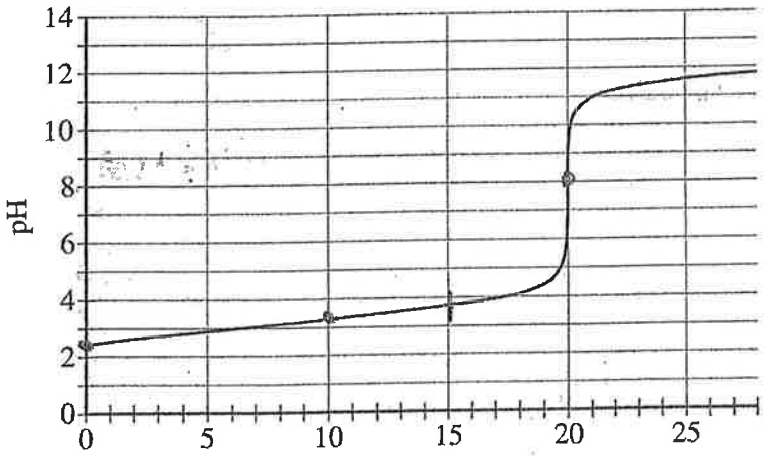


(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

nitrous acid $HNO_2(aq) + OH^-(aq) \rightarrow NO_2^-(aq) + H_2O(l)$

The following titration curve shows the change in pH of the solution during the titration.



2 mmol HNO_2 → ; xM =

(e) Use the titration curve and the information above to

(i) determine the initial concentration of the $HNO_2(aq)$ solution

(ii) estimate the value of pK_a for $HNO_2(aq)$

$pK_a \approx 3.4$ $K_a \approx 3.98 \times 10^{-4}$

(f) During the titration, after a volume of 15 mL of 0.100 *M* KOH(*aq*) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

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GO ON TO THE NEXT PAGE.

2A 3 of 3

a) In box on previous page.

b) i) $\Delta G^\circ = -RT \ln K$

$570\ J/mole\ rxn = -(8.314\ J/mol\ K)(298\ K)(\ln K)$

$\ln K = -0.35$

$K = e^{-0.35}$

$K = 0.70$

ii) No, $P_{N_2O_3}$ at equilibrium will not equal 1.00 atm, because the equilibrium constant K is <1, so the reaction lies mostly to the left, so $P_{N_2O_3}$ won't reach the initial pressures of the reactants.

c) No. By increasing temperature, the reaction shifts left according to LeChatlier's principle. The reaction is exothermic, and an increase in temp will cause the rxn to move left, producing less product to remedy this stress.

d) i) see box on previous page. Also: H - $\ddot{O}$ - $\ddot{N}$ = $\ddot{O}$:

ii) The hybridization of N in the above Lewis structure is sp^2.

e) i) @ equivalence pt:

$HNO_2 + OH^- \rightarrow NO_2^- + H_2O$ $\quad$ $x\,M\ HNO_2 = \frac{2\ mmol}{100.\ mL}$

2mmol 2mmol

$x = \boxed{0.0200\ M\ HNO_2}$

ii) The pKa value for $HNO_2 \approx 3.4$

f) $NO_2^-(aq)$ is present in higher concentration, because this is past the halfway point of the titration. 1.5 mmol NO_2^- are present, while only 0.5 mmol HNO_2 are present.

$HNO_2 + OH^- \rightarrow NO_2^- + H_2O$

2mmol 1.5mmol

0.5mmol 0 1.5mmol

GO ON TO THE NEXT PAGE.

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2B 1 of 4

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

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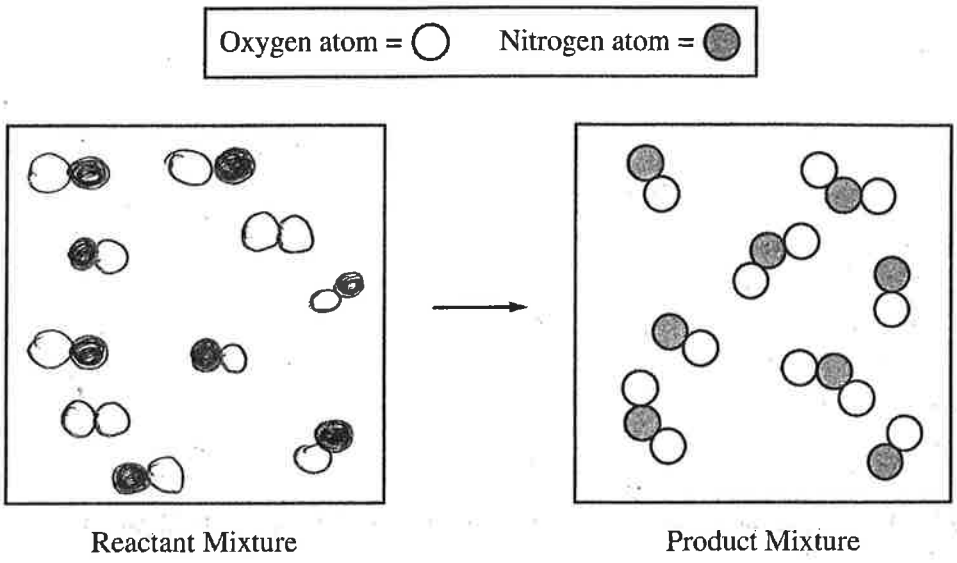

Reactant Mixture Product Mixture

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
-40.4 kJ/mol$_{rxn}$	-138.5 J/(K·mol$_{rxn}$)	0.87 kJ/mol$_{rxn}$

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

disagree

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GO ON TO THE NEXT PAGE.

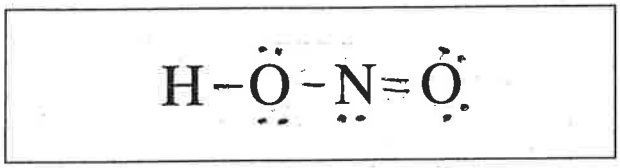
$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

$$N_2O_3(g) + H_2O(l) \rightarrow 2\,HNO_2(aq)$$

(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

18 e⁻



(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

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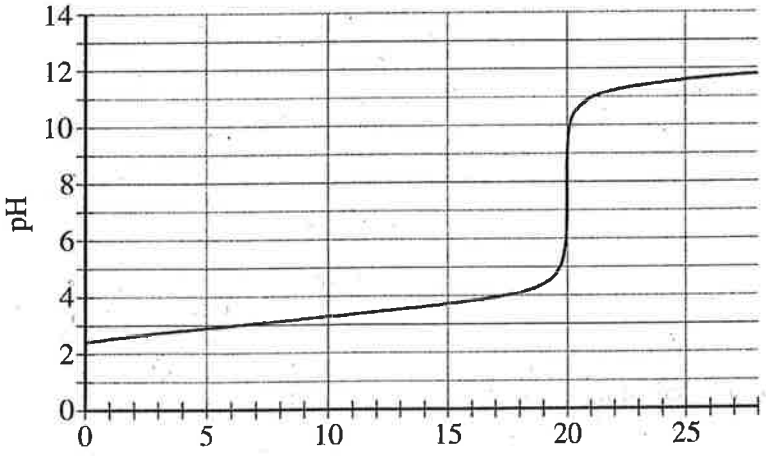

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2B 3 of 4

a) see diagram

b) i $\Delta G^\circ = -RT\ln K$

$\frac{\Delta G^\circ}{-RT} = \ln K$

$\frac{870\ J/mol}{-8.314\ J/(mol \cdot K) \cdot 298K} = \ln K$

$-.351 = \ln K$

$.704 = K$

ii No, if the reaction went to completion, pN_2O_3 would equal 1 atm, but since equilibrium is achieved before that, pN_2O_3 will be less than 1 atm

c) I disagree with this statement because the reaction is exothermic. According to Le'Chatlier's principle, adding heat to an exothermic reaction will cause the reactants to be favored, thus decreasing the amount of N_2O_3.

di see diagram

d) ii sp^2

e i moles acid = moles base

$.100\ M \cdot .020 = .002\ mol\ OH^-$

$.002\ mol\ OH^- = .002\ mol\ H^+$

$\frac{.002\ mol}{.1\ L} = .02\ mol/L\ HNO_2$

e ii pK_a = pH at half equivalence point = 3.4

f) HNO_2 is in higher concentration because the equivalence point has not been reached yet so moles acid > moles conjugate base at that point.

10:35 - 10:55

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2C 1 of 3

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

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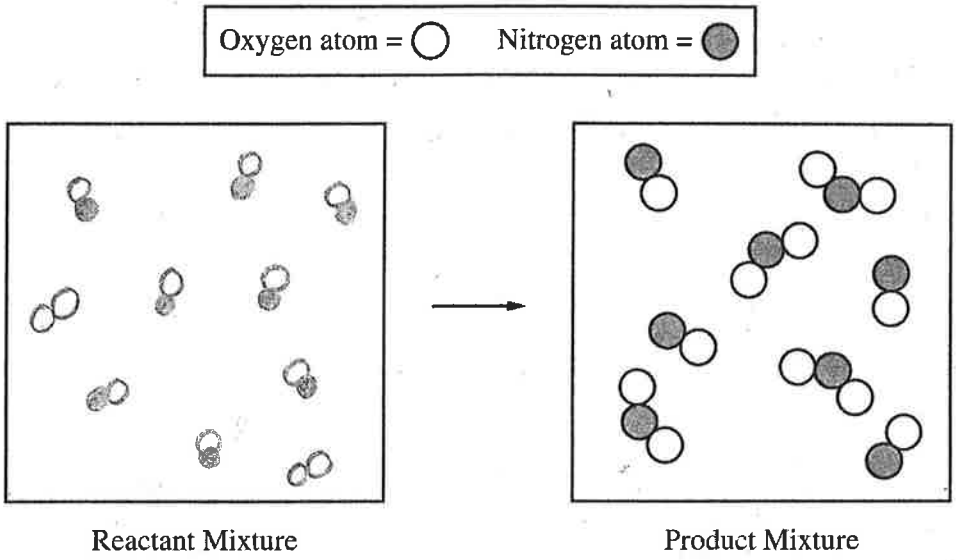

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$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

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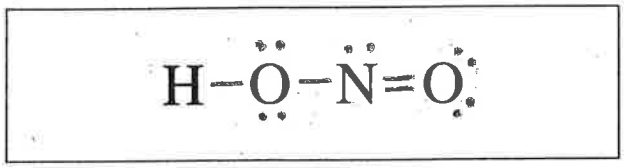
(d) The skeletal structure of the HNO_2 molecule is shown in the box below.

(i) Complete the Lewis electron-dot diagram of the HNO_2 molecule in the box below, including any lone pairs of electrons.

1+5+12

18 e⁻



(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

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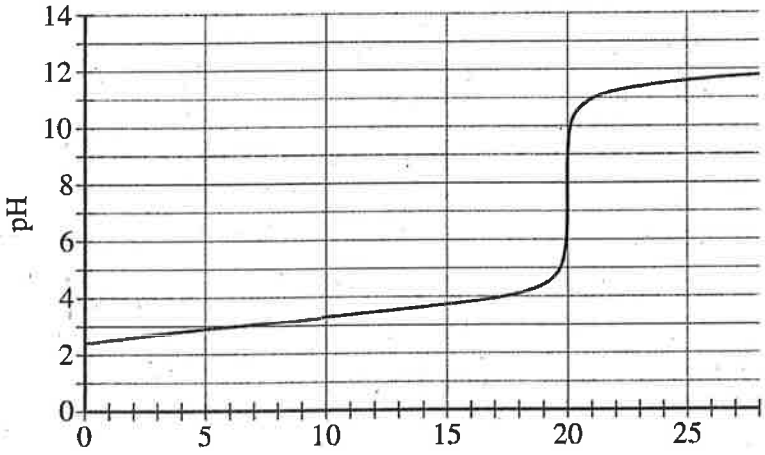

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b.i $\Delta G^\circ = -RT \ln K$ $.87 = -(8.314)(298) \ln K$ $\boxed{K = 1}$

ii Yes. $K_p = \frac{(N_2O_3)}{(NO)(NO_2)}$ $1 = \frac{(N_2O_3)}{(1)(1)}$ $\boxed{1 = P_{N_2O_3}}$

c. Disagree. A negative ΔH shows the reaction is exothermic, so heat is treated as a product and increasing the temp would cause a shift left toward the reactants.

dii sp^2

eii pH = pKa at 10mL $\boxed{pK_a \approx 3.3}$

f. NO_2^- is present in higher concentration after 15mL KOH is added. Halfway to the equivalence point (after 10mL KOH is added) is when HNO_2 and NO_2^- are in equal concentration, so beyond that there is a higher concentration of NO_2^- because the acid is being titrated out.

ei $M_A V_A = M_B V_B$ $(M_A)(100mL) = (.1M)(20mL)$ $M_A = \boxed{.02M\ HNO_2}$

GO ON TO THE NEXT PAGE.

8
4 2 4

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2D 1 of 4

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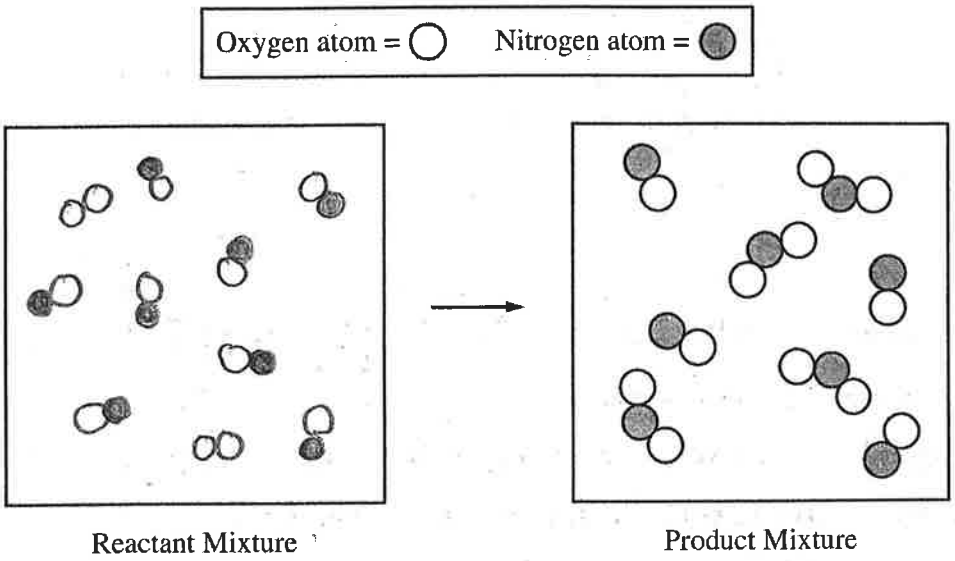

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The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g) + \text{heat}$$

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
$-40.4\ \text{kJ/mol}_{rxn}$	$-138.5\ \text{J/(K}\cdot\text{mol}_{rxn}\text{)}$	$0.87\ \text{kJ/mol}_{rxn}$

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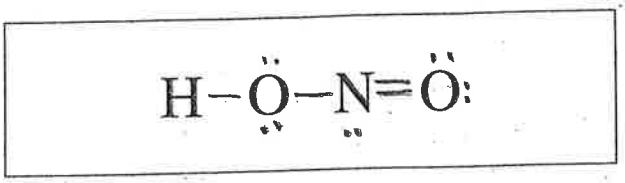

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To produce an aqueous solution of HNO_2, the student bubbles $N_2O_3(g)$ into distilled water. Assume that the reaction goes to completion and that HNO_2 is the only species produced. To determine the concentration of $HNO_2(aq)$ in the resulting solution, the student titrates a 100. mL sample of the solution with 0.100 *M* KOH(*aq*). The neutralization reaction is represented below.

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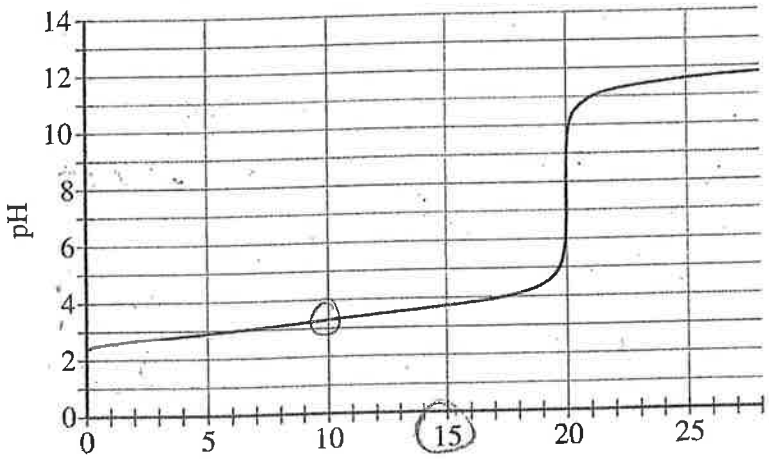

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GO ON TO THE NEXT PAGE.

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a) (drawing)

b) (i) $K = e^{\frac{-\Delta G}{RT}} = e^{-\left(\frac{0.87}{8.314 \cdot 298}\right)} = \boxed{1.00}$

(ii) yes $P = \frac{nRT}{V}$ ← all of this is constant each and same as reactant

c) disagree ∵ rxn is exothermic
⇒ favors low temperatures
⇒ increasing temperature will shift eq^m to reactants and thus decrease N_2O_3 produced

d) (i) (diagram)

(ii) sp^2

$[H^+] = \sqrt{K_a \cdot [HA]}$

e) (i) $-\log(2.5) = \sqrt{-\log(3.3) \cdot [HNO_2]}$

$[HNO_2] = 0.305M$

(ii) $pH = pK_a$ @ $\frac{1}{2}$ equivalence point ← 10 mL KOH added

$\boxed{pK_a \approx 3.3}$

f) NO_2^- ∵ @ $\frac{1}{2}$ equiv. point (10 mL)

moles HNO_2 = moles NO_2^-

past 10 mL more HNO_2 has been converted to NO_2^-

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$ 2E 1 of 4

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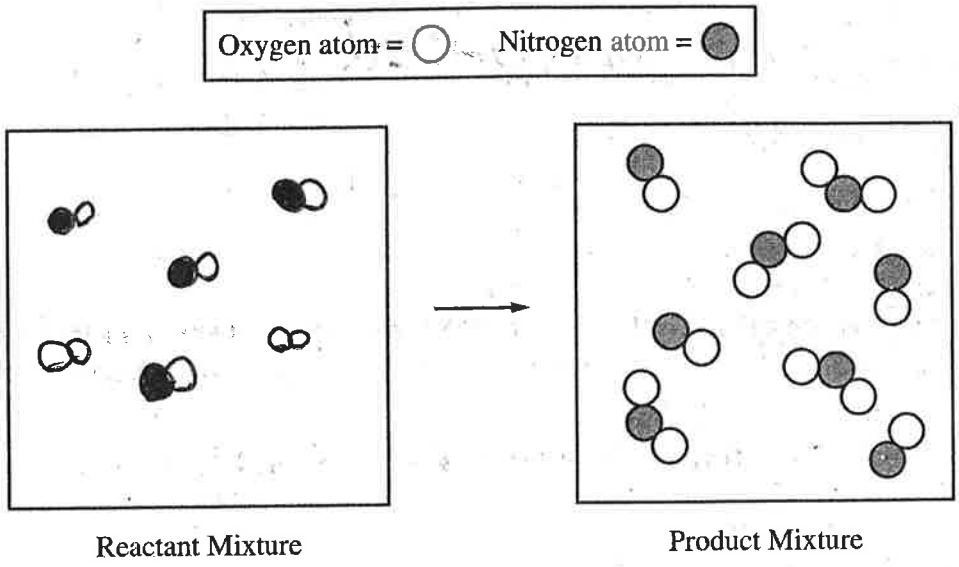

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$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$ +40.4 kJ/mol

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
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(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

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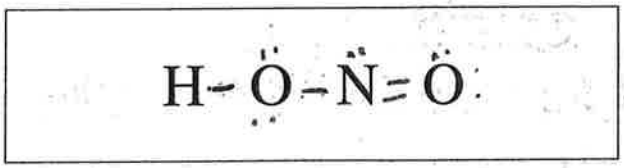

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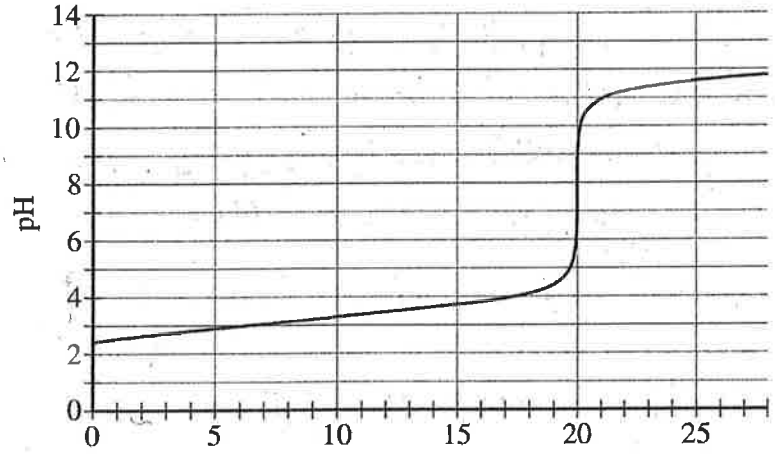

(e) Use the titration curve and the information above to

(i) determine the initial concentration of the $HNO_2(aq)$ solution $2.5 = -\log [H^+]$

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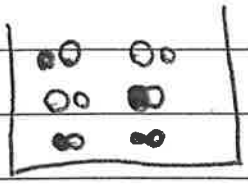
2E 3 of 4

a) In the drawing, there are twice as many NO as there are O_2.



b) (i) $\Delta G = -RT \ln k$

$0.87\ kJ/mol = -(8.314\ J\ mol^{-1}\ K^{-1})(298\ K) \ln k$

$870\ J/mol = -(8.314\ J\ mol^{-1}\ K^{-1})(298\ K) \ln k$

$k = 0.704$

(ii) No because since $k = 0.704$ are in the equilibrium constant equation $k = \frac{[products]}{[reactants]}$, $0.704 = \frac{[products]}{[1]^2}$ $P_{product} = 0.704$, thus $P_{N_2O_3}$ will not be 1 atm.

c) I disagree with the hypothesis because since ΔH is exothermic, it will lie on the products side. If one were to increase temperature then, by Le Chatelier's principle, the reaction will shift to the left creating less product or $N_2O_{3(g)}$.

d) (i) H – Ö – N = Ö: (ii) N, sp^2

e) (i) $pH = -\log[H^+]$

$2.5 = -\log[H^+]$

$[H^+] = 0.0032\ M$

GO ON TO THE NEXT PAGE.

ADDITIONAL PAGE FOR ANSWERING QUESTION 2

(ii) At half equivalence point, pH ≈ pKa
½ eq point is 10 mL, at 6 mL pH ≈ 3.2, therefore
pKa ≈ 3.2.

f) HNO_2 is present at a larger concentration when only 15 mL of 0.1 M NaOH(aq) is added because it is still before the equivalence point and thus by Henderson Hasselbalch Equation, the concentration of HNO_2 is higher.

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2F 1 of 3

2. A student investigates the reactions of nitrogen oxides. One of the reactions in the investigation requires an equimolar mixture of $NO(g)$ and $NO_2(g)$, which the student produces by using the reaction represented above.

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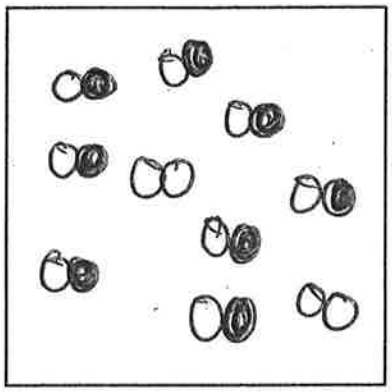
8 NO + 3O2 ⇌ 4NO + 4NO2

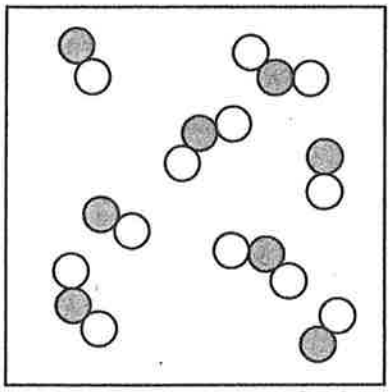
8N

Oxygen atom = ○ Nitrogen atom = ●

NO O2

80





4NO

80

120

Reactant Mixture

Product Mixture

4NO 4NO2

The student reads in a reference text that $NO(g)$ and $NO_2(g)$ will react as represented by the equation below. Thermodynamic data for the reaction are given in the table below the equation.

$$NO(g) + NO_2(g) \rightleftarrows N_2O_3(g)$$

ΔG = ΔH − TΔS°

ΔG = −RT ln K

K = e^(ΔG/−RT)

K = e^(ΔG/RT)

ΔH°_{298}	ΔS°_{298}	ΔG°_{298}
−40.4 kJ/mol$_{rxn}$	−138.5 J/(K·mol$_{rxn}$)	0.87 kJ/mol$_{rxn}$

(b) The student begins with an equimolar mixture of $NO(g)$ and $NO_2(g)$ in a rigid reaction vessel and the mixture reaches equilibrium at 298 K.

(i) Calculate the value of the equilibrium constant, K, for the reaction at 298 K.

(ii) If both P_{NO} and P_{NO_2} in the vessel are initially 1.0 atm, will $P_{N_2O_3}$ at equilibrium be equal to 1.0 atm? Justify your answer.

(c) The student hypothesizes that increasing the temperature will increase the amount of $N_2O_3(g)$ in the equilibrium mixture. Indicate whether you agree or disagree with the hypothesis. Justify your answer.

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$N_2O_3(g)$ reacts with water to form nitrous acid, $HNO_2(aq)$, a compound involved in the production of acid rain. The reaction is represented below.

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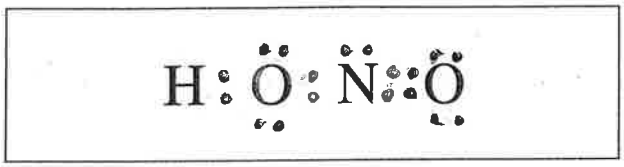

(ii) Based on your completed diagram above, identify the hybridization of the nitrogen atom in the HNO_2 molecule.

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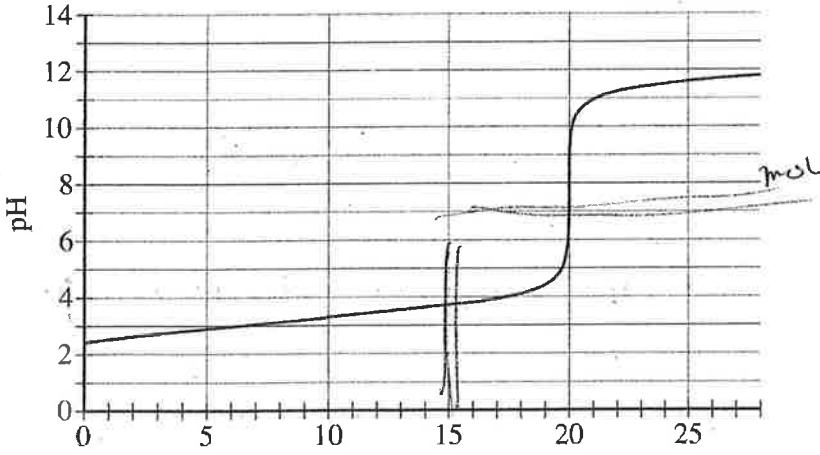

(e) Use the titration curve and the information above to

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(f) During the titration, after a volume of 15 mL of 0.100 *M* KOH(*aq*) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

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2F 3 of 3

b) i: ~~$\Delta G = \Delta H^\circ - T\Delta S$~~

$\Delta G = .87$ kj/mol $K = e^{(-.87/RT)}$ .008314 kj/mol

$K = e^{(-.87/(.008314 \cdot 298)}$ $\frac{R=8.314\text{ J}}{1000}$ $T = 298$ K

$K = .704$ $\boxed{K = .704}$

ii: ~~HNO_2, H_2O~~ N_2O_3 will have a pressure different than 1 atm because it has a different mass and concentration.

c) I disagree. The reaction is exothermic as it has a (-) ΔH. Therefore heat is a product. If you increase the heat it will shift to the reactants side to restore equilibrium. It will not create more N_2O_3 as that is a product.

d.) sp

e.) i) $ph = 2.3$ $10^{-2.3} = \boxed{.005M} = [HNO_2]$

ii) $pka = -\log(Ka)$ $pka = -.36$

f.) HNO_2 is at a higher concentration. It has not reached the equivalene point, and is still at an acidic pH. Therefor there is more acid, HNO_2 at 15 ml.

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2G 1 of 3

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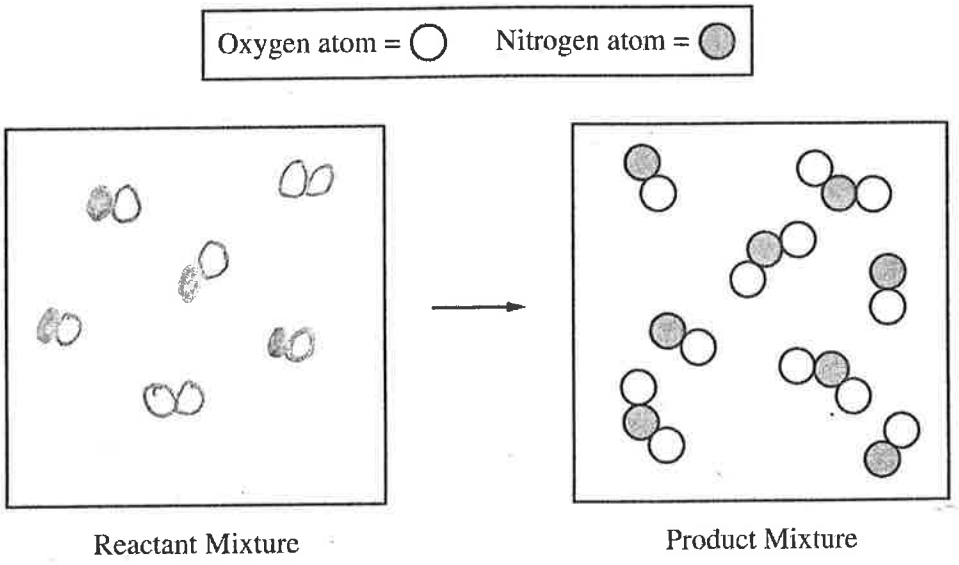

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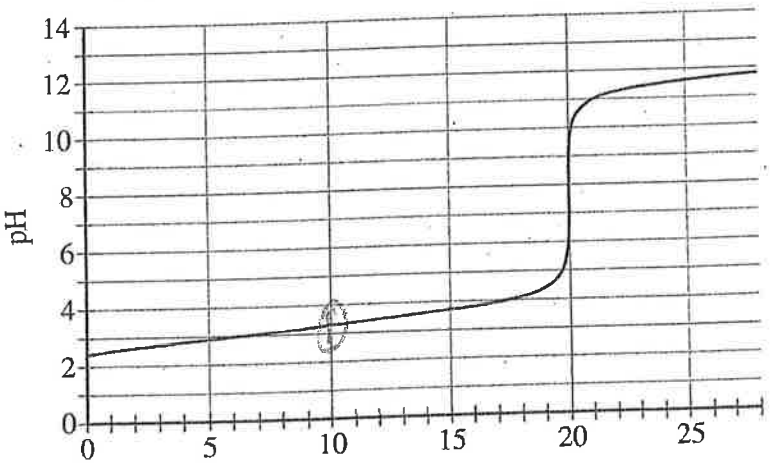

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b.) (i) $\Delta G = -RT \ln K$

$\ln K = \Delta G / -RT$

$K = e^{(.87 / -(8.314 \times 298))} = .99$

(ii) yes because the molar ratios of $NO : NO_2 : N_2O_3$ is $1 : 1 : 1$.

c.) The student is incorrect because the reaction is exothermic based off the $-\Delta H^\circ$ which means heat is a product. If heat is increased the reaction will shift away towards the reactants which will decrease the amount of N_2O_3 as stated by Le Chateliers principle.

d.) (ii) sp^3

(e.) (i) $10^{-2.5} = H^+ = HNO_2 = .0032\ M$

(ii) $pKa = 3.30$

(f.) After 15 ml of KOH has been added NO_2^- is higher in concentration because at this point the titration is after the half equivalence point and contains more of the conjugate base.

GO ON TO THE NEXT PAGE.

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2H, of 3

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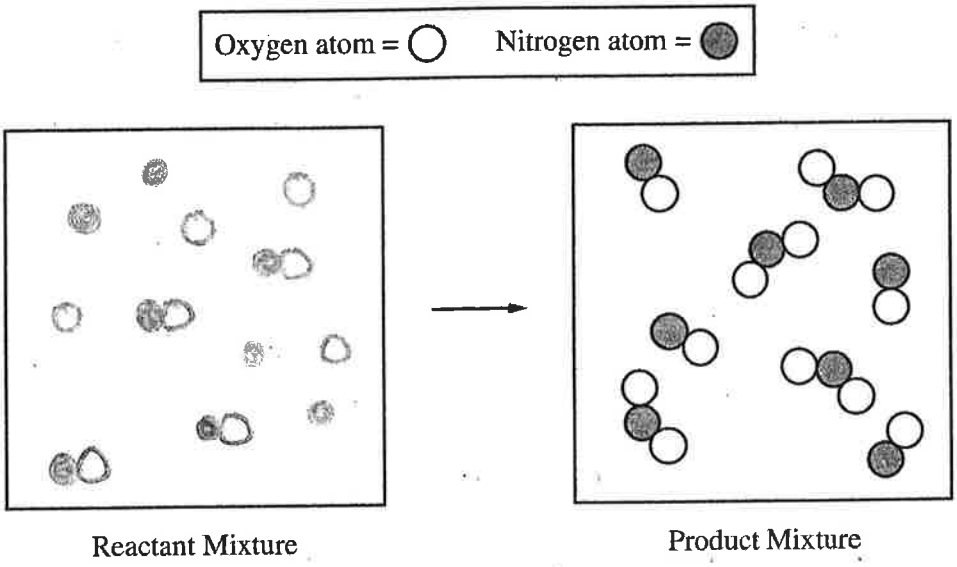

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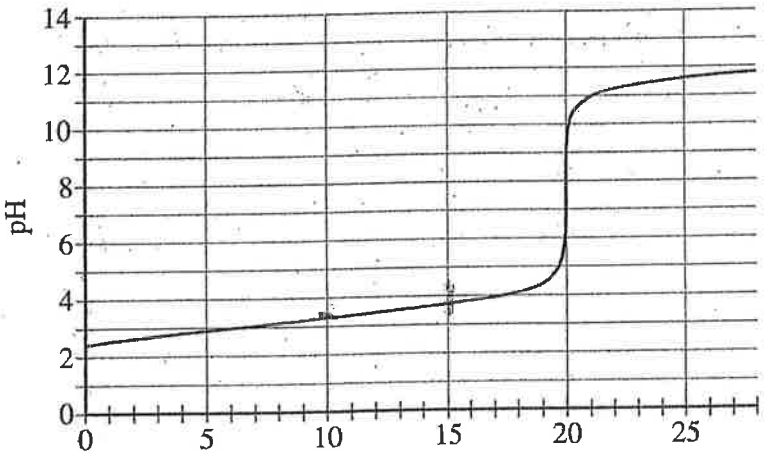

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2H 3 of 3

B)

i) $\Delta G = -RT\ln K$ $\quad E^{\Delta G/-RT} = K$

870 J/mol / −(8.134 J/mol·K × 298 K) $\quad K = 6.98 \times 10^{1}$

ii) YES BECAUSE THERE HAS BEEN NO STRESS PUT ON THE SYSTEM FOR THERE TO BE A CHANGE IN PRESSURE

C) YES BECAUSE IT IS AN ENDOTHERMIC REACTION SO WHEN HEAT IS ADDED IT WILL SHIFT RIGHT TOWARDS THE PRODUCTS INCREASING N_2O_3

D) iii) S^2p^3

E) i) INITIAL PH IS ≈2.5

ii) PKA ≈3.2

F) HNO_2 IS AT A HIGHER CONCENTRATION BECAUSE THE SOLUTION IS STILL IN THE ACIDIC RANGE, ALSO IT IS BEFORE THE EQUILIVANCE POINT MAKING THE ACID OUT WEIGHT THE BASE

$$2\,NO(g) + O_2(g) \rightarrow 2\,NO_2(g)$$

2I 1 of 4

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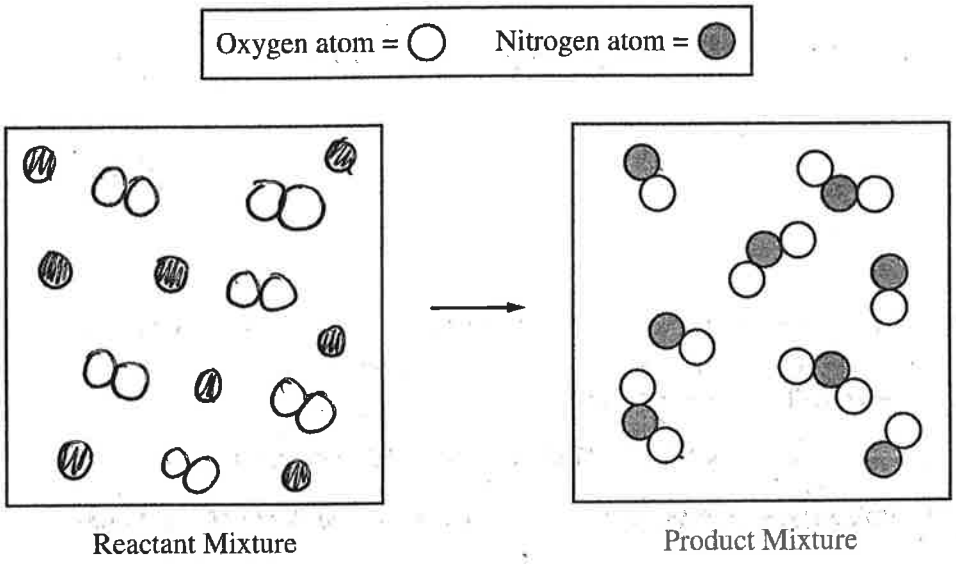

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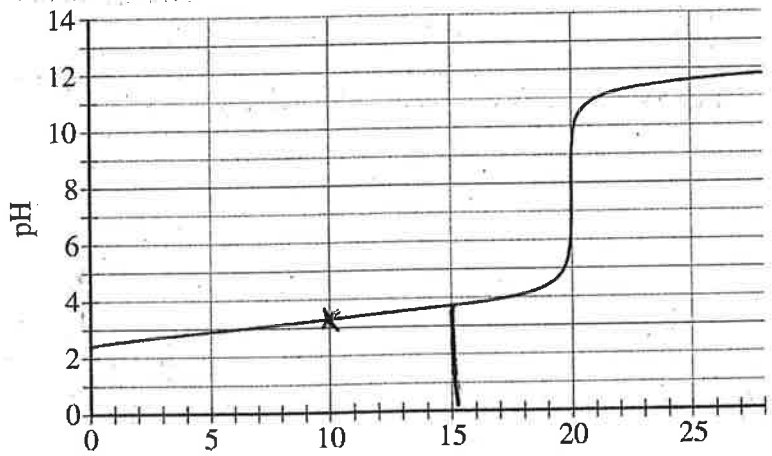

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2I 3 of 4

(b) (i) $\Delta G^\circ = -RT\ln K$

$0.87\ kJ/mol = 0.008314\ kJ/mol\cdot K\,(298K)\ln K \quad K = e^{0.351}$

$\boxed{K = 1.4}$

(ii) yes, $P_{N_2O_3}$ will be equal to 1.0 atm at equilibrium because $K = \frac{P_{N_2O_3}}{(P_{NO_2})(P_{NO})}$

and at equilibrium $K=1$ so $1 = \frac{P_{N_2O_3}}{(1\ atm)(1\ atm)}$

$P_{N_2O_3} = 1.0\ atm$

(c) I agree with the student's hypothesis because $\Delta H = -40.4\ kJ/mol$ therefore this reaction is exothermic so heat is a product, based on Le Chatlie's principle when heat is added as a reactant the reaction must shift right so more product will be made (N_2O_3 will be made)

(d) (ii) linear

(e) (i) $pH = -\log[H^+]$ initial $pH = 2.5$

$2.5 = -\log[H^+]$ $[H^+] = \boxed{0.082\ M = [HNO_2]}$

(ii) based on the titration curve $pK_a \approx 3.5$

(F) ~~$HNO_2 + OH^- \rightarrow NO_2^- + H_2O$~~

~~E~~

~~C~~

~~E~~

~~0.015 L KOH × 0.100 mol KOH / 1 L =~~

HNO_2 is present in higher concentration because according to the titration curve the solution has not reached equilibrium yet where moles acid = moles base and since we start with a low therefore acidic pH the acid is present in ~~excess~~ higher concentration and so it still is ^ in higher before the equivalence point where there is 15 mL of 0.100 M KOH

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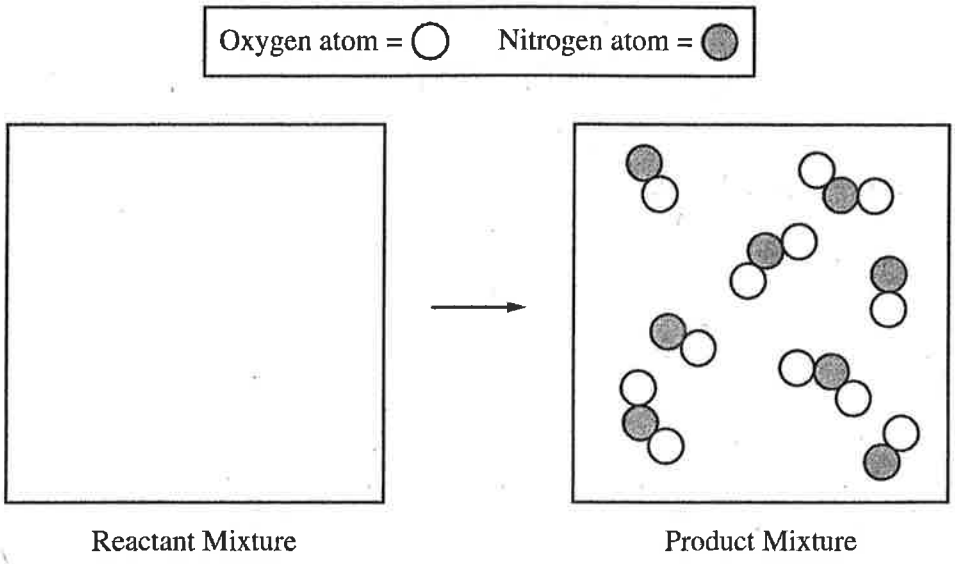

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1 5 8

H O N O

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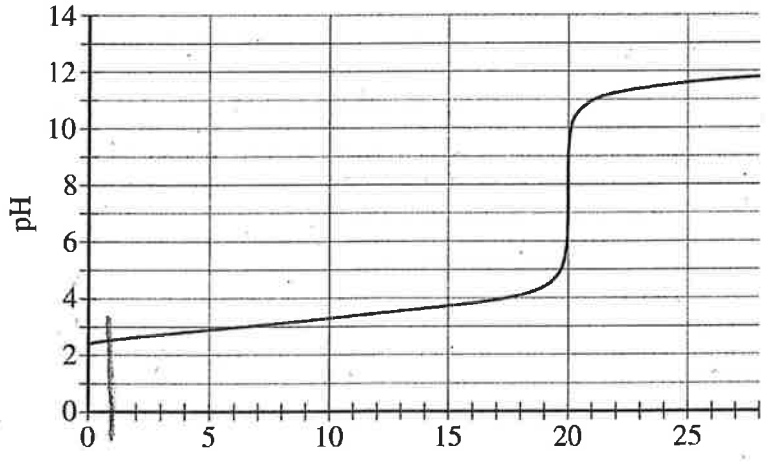

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(i) determine the initial concentration of the $HNO_2(aq)$ solution

(ii) estimate the value of pK_a for $HNO_2(aq)$

(f) During the titration, after a volume of 15 mL of 0.100 *M* KOH(*aq*) has been added, which species, $HNO_2(aq)$ or $NO_2^-(aq)$, is present at a higher concentration in the solution? Justify your answer.

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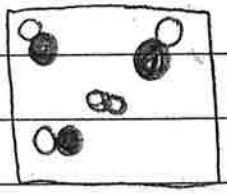
A reactant mixture 

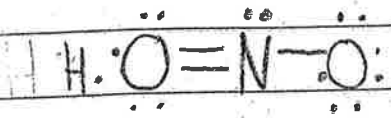
B $-40.4 = K(298)$

$K = -.135$

ii $P_{N_2O_3}$ will not be equal to 1.0 atm because there are 2 atoms of Nitrogen and it will not work.

C Increasing the temperature will increase amount of $P_{N_2O_3}$ because it will make the molecules move closer & create more space

D



ii hybridization of N =

e initial concentration = 2.5 $\left(\frac{2.5}{1}\right)$

$P_{KA} = -\log(K_A)$

$P_{KA} = -\log(56)$

$pKA = -1.75$

F) NO^{2-}

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Question 2

Sample Identifier: 2A
Score: 10

- In part (a), the student earned the full 2 points because the student drew the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 was shown, and the student correctly represented atom conservation.
- In part (b)(i), the student earned the point for correctly calculating K.
- In part (b)(ii), the student earned the point for the correct choice and valid justification.
- In part (c), the student earned the point for the correct choice and valid justification.
- In part (d)(i), the student earned the point for drawing the correct Lewis-dot diagram.
- In part (d)(ii), the student earned the point for the correct hybridization consistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student earned the point for correctly calculating the initial concentration of HNO_2.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student earned the point for correctly choosing the species present in higher concentration and with valid justification.

Sample Identifier: 2B
Score: 9

- In part (a), the student earned the full 2 points because the student drew the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 was shown, and the student correctly represented atom conservation.
- In part (b)(i), the student earned the point for correctly calculating K.
- In part (b)(ii), the student earned the point for the correct choice and valid justification.
- In part (c), the student earned the point for the correct choice and valid justification.
- In part (d)(i), the student earned the point for drawing the correct Lewis-dot diagram.
- In part (d)(ii), the student earned the point for the correct hybridization consistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student earned the point for correctly calculating the initial concentration of HNO_2.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student did not earn the point because the student chose the wrong species.

Sample Identifier: 2C
Score: 8

- In part (a), the student earned the full 2 points because the student drew the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 was shown, and the student correctly represented atom conservation.
- In part (b)(i), the student did not earn the point because the student incorrectly calculated K.
- In part (b)(ii), the student did not earn a point because of incorrect choice.
- In part (c), the student earned the point for the correct choice and valid justification.
- In part (d)(i), the student earned the point for drawing the correct Lewis-dot diagram.
- In part (d)(ii), the student earned the point for the correct hybridization consistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student earned the point for correctly calculating the initial concentration of HNO_2.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student earned the point because the student chose the right species with valid justification.

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Sample Identifier: 2D
Score: 7

- In part (a), the student earned the full 2 points because the student drew the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 was shown, and the student correctly represented atom conservation.
- In part (b)(i), the student did not earn the point because the student incorrectly calculated K.
- In part (b)(ii), the student did not earn the point because of incorrect choice.
- In part (c), the student earned the point for the correct choice and valid justification.
- In part (d)(i), the student earned the point for drawing the correct Lewis-dot diagram.
- In part (d)(ii), the student earned the point for the correct hybridization consistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student did not earn the point because the initial concentration of HNO_2 was incorrectly calculated.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student earned the point because the student chose the right species with valid justification.

Sample Identifier: 2E
Score: 6

- In part (a), the student earned 1 point because the student drew the correct particle-level representation for the reactant molecules NO and O_2 but did not earn the second point as atom conservation was not represented.
- In part (b)(i), the student earned the point for correctly calculating K.
- In part (b)(ii), the student did not earn the point because there was no valid justification for the right choice.
- In part (c), the student earned the point for the correct choice and valid justification.
- In part (d)(i), the student earned the point for drawing the correct Lewis-dot diagram.
- In part (d)(ii), the student earned the point for the correct hybridization consistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student did not earn the point because the initial concentration of HNO_2 was incorrectly calculated.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student did not earn the point because the student chose the wrong species.

Sample Identifier: 2F
Score: 5

- In part (a), the student earned the full 2 points because the student drew the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 was shown, and the student correctly represented atom conservation.
- In part (b)(i), the student earned the point for correctly calculating K.
- In part (b)(ii), the student did not earn the point because of an invalid justification.
- In part (c), the student earned the point for the correct choice and valid justification.
- In part (d)(i), the student earned the point for drawing the correct Lewis-dot diagram.
- In part (d)(ii), the student did not earn the point because the hybridization was inconsistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student did not earn the point because the initial concentration of HNO_2 was incorrectly calculated.
- In part (e)(ii), the student did not earn the point because of incorrect estimation of the value of pK_a for HNO_2.
- In part (f), the student did not earn the point because the student chose the wrong species.

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Sample Identifier: 2G
Score: 4

- In part (a), the student earned 1 point because the student drew the correct particle-level representation for the reactant molecules NO and O_2 but did not earn the second point since atom conservation was not represented.
- In part (b)(i), the student did not earn the point because the student incorrectly calculated K.
- In part (b)(ii), the student did not earn a point because of an incorrect choice.
- In part (c), the student earned the point for the correct choice and valid justification.
- In part (d)(i), the student did not earn the point because of incorrect Lewis-dot diagram.
- In part (d)(ii), the student did not earn the point because the hybridization was inconsistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student did not earn the point because of the incorrect calculation of the initial concentration of HNO_2.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student earned the point for the right choice and valid justification.

Sample Identifier: 2H
Score: 3

- In part (a), the student did not earn any points because the student did not draw the correct particle-level representation; the correct representation for the reactant molecules NO and O_2 was missing, and the student did not represent atom conservation.
- In part (b)(i), the student earned the point for correctly calculating K.
- In part (b)(ii), the student did not earn the point because of incorrect choice.
- In part (c), the student did not earn the point because of incorrect choice.
- In part (d)(i), the student earned the point for drawing the correct Lewis-dot diagram.
- In part (d)(ii), the student did not earn the point because the hybridization was inconsistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student did not earn the point because the student incorrectly calculated the initial concentration of HNO_2.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student did not earn the point because the student chose the wrong species.

Sample Identifier: 2I
Score: 2

- In part (a), the student earned 1 point for atom conservation but did not earn the point for correctly representing the reactant molecules NO and O_2.
- In part (b)(i), the student did not earn the point because of incorrectly calculating K.
- In part (b)(ii), the student did not earn the point because of the wrong choice.
- In part (c), the student did not earn the point because of the wrong choice.
- In part (d)(i), the student did not earn the point because of incorrect Lewis-dot diagram.
- In part (d)(ii), the student did not earn the point because the student gave no hybridization but rather gave the geometry about N consistent with the Lewis-dot diagram in (d)(i).
- In part (e)(i), the student did not earn a point because of incorrectly calculating the initial concentration of HNO_2.
- In part (e)(ii), the student earned the point for correctly estimating the value of pK_a for HNO_2.
- In part (f), the student did not earn the point because the student chose the wrong species.

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Sample Identifier: 2J
Score: 1

- In part (a), the student earned 1 point for correctly representing the reactant molecules NO and O_2 but did not earn the second point for representing atom conservation.
- In part (b)(i), the student did not earn the point because of incorrectly calculating K.
- In part (b)(ii), the student did not earn the point because the right choice had an invalid justification.
- In part (c), the student did not earn the point because of the wrong choice.
- In part (d)(i), the student did not earn the point because of an incorrect Lewis-dot diagram.
- In part (d)(ii), the student did not earn the point because the student gave no hybridization.
- In part (e)(i), the student did not earn a point because of incorrectly calculating the initial concentration of HNO_2.
- In part (e)(ii), the student did not earn the point because of incorrectly estimating the value of pK_a for HNO_2.
- In part (f), the student did not earn the point because the student wrote the formula of the species incorrectly and did not supply a justification.

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3. Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(a) Write the ground-state electron configuration of the Fe^{2+} ion.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

A student obtains a solution that contains an unknown concentration of $Fe^{2+}(aq)$. To determine the concentration of $Fe^{2+}(aq)$ in the solution, the student titrates a sample of the solution with $MnO_4^-(aq)$, which converts $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$, as represented by the following equation.

$$5\ Fe^{2+}(aq) + MnO_4^-(aq) + 8\ H^+(aq) \rightarrow 5\ Fe^{3+}(aq) + Mn^{2+}(aq) + 4\ H_2O(l)$$

(d) Write the balanced equation for the half-reaction for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

(e) The student titrates a 10.0 mL sample of the $Fe^{2+}(aq)$ solution. Calculate the value of $[Fe^{2+}]$ in the solution if it takes 17.48 mL of added 0.0350 *M* $KMnO_4(aq)$ to reach the equivalence point of the titration.

To deliver the 10.0 mL sample of the $Fe^{2+}(aq)$ solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret
- 25 mL beaker
- 25 mL graduated cylinder
- 25 mL volumetric flask

(f) Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the $Fe^{2+}(aq)$ solution.

In a separate experiment, the student is given a sample of powdered $Fe(s)$ that contains an inert impurity. The student uses a procedure to oxidize the $Fe(s)$ in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

Mass of $Fe(s)$ with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

(h) Calculate the percent by mass of Fe in the original sample of powdered $Fe(s)$ with the inert impurity.

(i) If the oxidation of the $Fe(s)$ in the original sample was incomplete so that some of the 7.531 g of product was $FeO(s)$ instead of $Fe_2O_3(s)$, would the calculated mass percent of $Fe(s)$ in the original sample be higher, lower, or the same as the actual mass percent of $Fe(s)$? Justify your answer.

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Question 3

Answer the following questions relating to Fe and its ions, Fe^{2+} and Fe^{3+}.

(a) Write the ground-state electron configuration of the Fe^{2+} ion.

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$ OR [Ar] $3d^6$	1 point is earned for a correct electron configuration.

Ion	Ionic Radius (pm)
Fe^{2+}	92
Fe^{3+}	79

(b) The radii of the ions are given in the table above. Using principles of atomic structure, explain why the radius of the Fe^{2+} ion is larger than the radius of the Fe^{3+} ion.

Both ions have the same nuclear charge. However, the greater number of electrons in the outermost shell of Fe^{2+} results in greater electron-electron repulsion within that shell, leading to a larger radius.	1 point is earned for a valid explanation.

(c) Fe^{3+} ions interact more strongly with water molecules in aqueous solution than Fe^{2+} ions do. Give one reason for this stronger interaction, and justify your answer using Coulomb's law.

Coulomb's law: $F \propto \frac{q_1\ q_2}{r^2}$ (need not be explicitly stated) In comparison to the Fe^{2+} ion, the Fe^{3+} ion has a higher charge. OR The smaller size of Fe^{3+} allows it to get closer to a water molecule.	1 point is earned for a valid explanation.

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Question 3 (continued)

A student obtains a solution that contains an unknown concentration of $Fe^{2+}(aq)$. To determine the concentration of $Fe^{2+}(aq)$ in the solution, the student titrates a sample of the solution with $MnO_4^-(aq)$, which converts $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$, as represented by the following equation.

$$5\ Fe^{2+}(aq) + MnO_4^-(aq) + 8\ H^+(aq) \rightarrow 5\ Fe^{3+}(aq) + Mn^{2+}(aq) + 4\ H_2O(l)$$

(d) Write the balanced equation for the half-reaction for the oxidation of $Fe^{2+}(aq)$ to $Fe^{3+}(aq)$.

$Fe^{2+}(aq) \rightarrow Fe^{3+}(aq) + e^-$	1 point is earned for the correct half-reaction.

(e) The student titrates a 10.0 mL sample of the $Fe^{2+}(aq)$ solution. Calculate the value of $[Fe^{2+}]$ in the solution if it takes 17.48 mL of added 0.0350 M $KMnO_4(aq)$ to reach the equivalence point of the titration.

$17.48\ \text{mL} \times \frac{0.0350\ \text{mol KMnO}_4}{1000\ \text{mL}} = 0.000612\ \text{mol KMnO}_4$ $0.000612\ \text{mol KMnO}_4 \times \frac{5\ \text{mol Fe}^{2+}}{1\ \text{mol KMnO}_4} = 0.003059\ \text{mol Fe}^{2+}$ $\frac{0.003059\ \text{mol Fe}^{2+}}{0.0100\ \text{L}} = 0.306\ M\ Fe^{2+}$	1 point is earned for calculating the number of moles of $KMnO_4$ (may be implicit). 1 point is earned for the correct concentration of $Fe^{2+}(aq)$.

To deliver the 10.0 mL sample of the $Fe^{2+}(aq)$ solution in part (e), the student has the choice of using one of the pieces of glassware listed below.

- 25 mL buret
- 25 mL beaker
- 25 mL graduated cylinder
- 25 mL volumetric flask

(f) Explain why the 25 mL volumetric flask would be a poor choice to use for delivering the required volume of the $Fe^{2+}(aq)$ solution.

The volumetric flask is designed to contain only 25.00 mL precisely.	1 point is earned for a valid explanation.

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Question 3 (continued)

In a separate experiment, the student is given a sample of powdered Fe(s) that contains an inert impurity. The student uses a procedure to oxidize the Fe(s) in the sample to $Fe_2O_3(s)$. The student collects the following data during the experiment.

Mass of Fe(s) with inert impurity	6.724 g
Mass of $Fe_2O_3(s)$ produced	7.531 g

(g) Calculate the number of moles of Fe in the $Fe_2O_3(s)$ produced.

$7.531\ \text{g } Fe_2O_3 \times \frac{1\ \text{mol } Fe_2O_3}{159.70\ \text{g } Fe_2O_3} = 0.04716\ \text{mol } Fe_2O_3$ $0.04716\ \text{mol } Fe_2O_3 \times \frac{2\ \text{mol Fe}}{1\ \text{mol } Fe_2O_3} = 0.09431\ \text{mol Fe}$	1 point is earned for correct calculation.

(h) Calculate the percent by mass of Fe in the original sample of powdered Fe(s) with the inert impurity.

$0.09431\ \text{mol Fe} \times \frac{55.85\ \text{g Fe}}{1\ \text{mol}} = 5.267\ \text{g Fe}$ $\frac{5.267\ \text{g Fe}}{6.724\ \text{g Sample}} \times 100 = 78.33\%$	1 point is earned for correct calculation of the mass percent based on the answer to part (g).

(i) If the oxidation of the Fe(s) in the original sample was incomplete so that some of the 7.531 g of product was FeO(s) instead of $Fe_2O_3(s)$, would the calculated mass percent of Fe(s) in the original sample be higher, lower, or the same as the actual mass percent of Fe(s)? Justify your answer.

The calculated mass percent of Fe would be lower than the actual mass percent of Fe. A sample that contains any FeO (rather than Fe_2O_3) will have a higher actual mass percent of Fe than a completely oxidized sample would have. Therefore, when the moles of Fe are calculated (assuming all the mass of the sample is Fe_2O_3) the calculated number of moles of Fe, and hence the calculated mass percent of Fe, will be lower.	1 point is earned for the correct answer and a valid explanation.

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(a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^6$

(b) The Fe^{2+} ion contains more electrons, thus more repulsion occurs between the electrons, increasing the space they occupy. Fe^{3+} has less electrons and thus less repulsion, as well as having the same nuclear charge pulling in fewer electrons.

(c) Fe^{3+} ions have a higher charge than Fe^{2+} and therefore will more strongly attract the negative dipoles on water molecules. In addition, their smaller ionic radius means the attractive positive charge will be closer to the H_2O molecule, furthering the attractive forces.

(d) $Fe^{2+} \longrightarrow Fe^{3+} + e^-$

(e) $\frac{.0350\ mol\ KMnO_4}{1\ L} = \frac{x\ mol}{.0174\ L} = 6.12 \times 10^{-4}\ mol\ KMnO_4 \cdot \frac{5\ mol\ Fe^{2+}}{1\ mol\ MnO_4^-} = 0.00306\ mol\ Fe^{2+}$

$\frac{0.00306\ mol\ Fe^{2+}}{1.01\ L} = \boxed{0.306\ M\ Fe^{2+}}$

(f) The volumetric flask only takes a reading at 25 mL, thus when using it you cannot tell when the inside volume of solution has reached 10mL. In addition, it does not measure to a decimal place, as with a beaker, further limiting its use.

(g) $7.531\ g\ Fe_2O_3 \cdot \frac{1\ mol}{159.70\ g\ Fe_2O_3} \cdot \frac{2\ mol\ Fe}{1\ mol\ Fe_2O_3} = \boxed{0.0943\ mol\ Fe}$

(h) $0.0943 \text{ mol Fe} \cdot \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 5.27 \text{ g Fe}$

$\frac{5.27 \text{ g Fe}}{6.724 \text{ g}} \times 100\% = \boxed{78.3\%}$

(i) The calculated mass percent would be lower as FeO has a lower molar mass than Fe_2O_3 and therefore increases the moles of iron present when calculated. With simply Fe_2O_3 being assumed to be produced, the moles of iron are reduced due to the difference in molar mass.

PAGE FOR ANSWERING QUESTION 3

a) $[Ar]3d^6$

b) The radius of Fe^{2+} is greater than the radius of Fe^{3+} because the number of electrons in Fe^{2+} are greater. Each ion has the same effective nuclear charge, but Fe^{3+} electrons will feel a greater pull because there are fewer electrons to absorb the pull.

c) Fe^{3+} ions are more positive than Fe^{2+}, so the surrounding water molecules will be more attracted to Fe^{3+} on the negative side of their dipole.

d)

$Fe^{2+}(aq) \rightarrow 1\bar{e} + Fe^{3+}(aq)$

e) $17.48\,mL\left(\frac{1\,L}{10^3\,mL}\right)\left(\frac{0.0350\,mol\,KMnO_4}{1\,L}\right)\left(\frac{5\,mol\,Fe^{2+}}{1\,mol\,KMnO_4}\right) = 0.003059\,mol\,Fe^{3+}$

$\frac{0.003509\,mol\,Fe^{2+}}{10.0\,mL\left(\frac{1\,L}{10^3\,mL}\right)} = 0.306\,M\,Fe^{2+}$

f) The volumetric flask would be a poor choice because it can only measure 25mL and no other volume. This would result in an incredibly inaccurate amount of Fe^{2+} solution being delivered.

g) $7.531\,g\,Fe_2O_3\left(\frac{1\,mol}{159.7\,g}\right)\left(\frac{2\,mol\,Fe}{1\,mol\,Fe_2O_3}\right) = 0.09431\,mol\,Fe$

h) $0.09431\,mol\,Fe\left(\frac{55.85\,g}{1\,mol}\right) = 5.267\,g\,Fe$

$\frac{5.627\,g\,Fe}{6.724\,g\,Fe(s)} \times 100\% = 78.34\%$

i) The mass percent would be lower because Fe is heavier than O, and some of the mass of Fe would be attributed to Oxygen instead of Fe. This would make the mass percent lower.

GO ON TO THE NEXT PAGE.

3C 1 of 2

a) $[Ar]\,3d^6$

b) The ionic radius of Fe^{2+} is larger than the ionic radius of Fe^{3+}, because Fe^{2+} has 1 more electron that exerts repulsive forces on the rest of the electron cloud. Also, in Fe^{3+} there are 3 less electrons compared to its nuclear charge (compared to 2 less in Fe^{2+}), so the electron cloud is more strongly attracted to the nucleus.

c) Fe^{3+} ions interact more strongly with H_2O because they have a greater charge, e.g.

$F = \frac{k q_1 q_2}{r^2}$ $\qquad \frac{k(3)(1)}{r^2} > \frac{k(2)(1)}{r^2}$

d) $Fe^{2+}_{(aq)} \longrightarrow Fe^{3+}_{(aq)} + e^-$

e) $M = \frac{\text{mol}}{L}$ $\qquad$ mol $= (.0350M)(17.48mL \times \frac{1L}{1000mL}) = 6.12 \times 10^{-4}$ moles $KMnO_4$

6.12×10^{-4} moles $KMnO_4 \times \frac{1 \text{ mole } MnO_4^-}{1 \text{ mole } KMnO_4} \times \frac{5 \text{ mole } Fe^{2+}}{1 \text{ mole } MnO_4^-} = .00306$ moles Fe^{2+}

$M = \frac{\text{mol}}{L} = .00306 \text{ moles} / (10.0mL \times \frac{1L}{1000mL})$

$[Fe^{2+}] = \boxed{.306\,M}$

f) The 25mL volumetric flask will be too large to accurately measure 10.0mL of the solution, and a buret is a better choice for measuring volumes in a titration.

GO ON TO THE NEXT PAGE.

g) $7.531\text{g } Fe_2O_3 \times \frac{1\text{mole } Fe_2O_3}{159.70\text{g}} \times \frac{2\text{moles Fe}}{1\text{mole } Fe_2O_3} = \boxed{.0943\text{moles Fe}}$

$2(55.85) + 3(16.00) = 159.70\text{g}$

h) $.0943\text{moles Fe} \times \frac{55.85\text{g}}{1\text{mole Fe}} = 5.267\text{g Fe}$

$\frac{5.267\text{g}}{6.724\text{g}} \times 100\% = \boxed{78.33\%}$

i) The calculated mass percent of Fe would be higher than the actual mass percent, because there is one Fe for every mole of FeO, instead of two for every mole of Fe_2O_3.

3D 1 of 2

3. a. ~~[Ar] 4s² 3d⁶~~

[Ar] $3d^6$

b. The radius of the Fe^{2+} ion is larger because the Fe atom has only lost 2 electrons. The Fe^{3+} ion has lost 3 electrons, which reduces the size of the ion more. Thus, Fe^{2+} has a smaller radius.

c. Coulomb's Law states that how strongly one molecule interacts with another depends on the charges and distance between the molecules. Charges, however, have a much greater effect on interactions than distance does. The Fe^{3+} ion is more charged than Fe^{2+}, and thus interacts more strongly with water molecules.

d. $5Fe^{2+} \rightarrow 5Fe^{3+}$

$Fe^{2+} \rightarrow Fe^{3+} + e^-$

e. $\frac{.0350 \text{ mol } MnO_4^-}{1 \text{ L}} \times .01748 \text{ L} = 6.118 \times 10^{-4} \text{ mol } MnO_4^- \text{ needed}$

$6.118 \times 10^{-4} \text{ mol } MnO_4^- \times \frac{5 \text{ mol } Fe^{2+}}{1 \text{ mol } MnO_4^-} = .003059 \text{ mol } Fe^{2+} \text{ needed}$

$\frac{.003059 \text{ mol } Fe^{2+}}{.01 \text{ L}} = .3059 \text{ M } Fe^{2+}$

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

f. A 25 ml volumetric flask would be a poor choice for delivering the Fe^{2+} because volumetric flasks are meant primarily for transferring gases, and thus are not typically marked with volumes of liquids. The volume of Fe^{2+} may not be measured precisely if the student uses a volumetric flask.

g. $7.531\ g\ Fe_2O_3 \times \frac{1\ mol\ Fe_2O_3}{159.7\ g} \times \frac{2\ mol\ Fe}{1\ mol\ Fe_2O_3} =$

$.0943$ mol Fe

h. $.0943\ mol\ Fe \times \frac{55.85\ g}{1\ mol} = 5.267\ g\ Fe$

$\frac{5.267\ g\ Fe(pure)}{6.724\ g\ Fe(impure)} \times 100 = 78.33\%$ pure Fe

i. The calculated mass percent of Fe(s) would be lower because FeO has less Fe in it than Fe_2O_3 does. Thus, the mass percentage would have originally presumed that for every mol Fe_2O_3, there were 2 mol Fe instead of some with 1 mol of FeO for 1 mol Fe.

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PAGE FOR ANSWERING QUESTION 3

a $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^4$

b The effective nuclear charge of the valance electrons is greater for Fe^{+3} ions as they have less of the positive charge of the nucleus to share among the valance electrons. Thus, the valance electrons are more closer making the radii of Fe^{+3} smaller

c Fe^{+3} has a stronger net charge meaning it would more likely reaction with other species with negative charges compared to Fe^{+2}. From ~~$\frac{q_1 q_2}{r^2}$~~ of Coulumb's law, we see that a stronger charge for Fe^{+3} (q) and and smaller distance (r) means greater attraction.

d. $1Fe^{+2}_{(aq)} \rightarrow 1Fe^{+3}_{(aq)} + 1e^-$

e $\frac{17.48\ mL}{10.0\ mL\ Fe^{+2}} \cdot \frac{1\ L}{1000\ mL} \cdot \frac{0.0390\ mol\ KMnO_4}{1\ L} \cdot \frac{5\ mol\ Fe^{+2}}{1\ mol\ KMnO_4} \cdot \frac{1000\ mL\ Fe^{+2}}{1\ L\ Fe^{+2}} = 0.306\ M$

f The flask has no specific markings to determine to 17.48 mL needed for the solution.

g $7.531\ g\ Fe_2O_3 \cdot \frac{1\ mol\ Fe_2O_3}{159.70\ g\ Fe_2O_3} \cdot \frac{2\ mol\ Fe}{1\ mol\ Fe_2O_3} = \boxed{0.09431\ mol\ Fe}$

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ADDITIONAL PAGE FOR ANSWERING QUESTION 3

h From g: $0.09431 \text{ mol Fe} \cdot \frac{55.85 \text{ g Fe}}{1 \text{ mol Fe}} = 5.267 \text{ g Fe}$

$\frac{5.267 \text{ g Fe}}{6.724 \text{ g Fe Impure}} \cdot 100\% = \boxed{78.33\% \text{ Fe}}$

i The calculated percent mass would be lower than the actual percent mass. This is FeO has less of a mole ration of $\frac{Fe}{O}$ and thus some Fe mass would be accounted as O mass in calculations of the moles of Fe. This in turn caused Fe mass to decrease and the percent mass to decrease as well.

PAGE FOR ANSWERING QUESTION 3

3a. $4s^2 4p^6 3d^4$

3b. The Fe^{3+} ion has ~~an effective~~ one less electron than the Fe^{2+} ion. Because the two have the same effective nuclear charge, this one-electron difference means that the nucleus of Fe^{3+} is able to pull its valence shell in tighter due to the absence of one more opposing force / charge.

3c. According to Coulomb's law, a greater charge, paired with a smaller ionic radius, will make an ion more attractive / electronegative. Fe^{3+} has a greater charge than Fe^{2+} ($3 > 2$) and a smaller ~~atomic~~ ionic radius ($79 < 92$). Because water is polar, Fe^{3+} will interact more strongly with the O^{2-} end of the water molecule than Fe^{2+}.

3d. $5Fe^{2+}_{(aq)} \rightarrow 5Fe^{3+}_{(aq)}$

$5Fe^{2+}_{(aq)} \rightarrow 5Fe^{3+}_{(aq)} + 5e^-$

$Fe^{2+}_{(aq)} \rightarrow Fe^{3+}_{(aq)} + 1e^-$

3e. $0.01748 \frac{\text{mol}}{\text{L}}$ ~~KMnO4~~ KMnO4 $\times \frac{0.0350 \text{ mol}}{\text{L}} = 6.118 \times 10^{-4}$ mol KMnO4

6.118×10^{-4} mol $\times 5 = 0.003059$ mol Fe^{2+}

~~0.003059 mol Fe^{2+}~~ $\div \frac{0.003059 \text{ mol } Fe^{2+}}{0.0100 \text{ L } Fe^{2+}} = 0.306$ M

3f. The volumetric flask doesn't have upright, straight sides, so the titration will not be consistent. The solution should be allowed to consistently drip down without volume/space being altered.

3g. $7.531 \text{ g } Fe_2O_3 \times \frac{\text{mol } Fe_2O_3}{159.7 \text{ g } Fe_2O_3} = 0.047162$ mol Fe_2O_3

3h. $55.85 \times 2 \times 0.047162 \text{ mol} = 6.436$ g F

$\frac{6.436 \text{ g}}{6.724 \text{ g}} \times 100\% = 95.72\%$

3i. The mass percent would be the same – FeO has a different molar mass, so that would even out the calculations

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3G 1 of 1

a) Fe^{2+} : $1s^2\,2s^2\,2p^6\,3s^2\,3p^6\,4s^2\,3d^4$

d) $5Fe^{2+} \rightarrow 5Fe^{3+} + 5e^-$

e) $(0.011\,L)\,x = (0.017448\,L)(0.0350\,M)$

$x = 0.0612\,M\ Fe^{2+}$

f) Using a 25 mL volumetric flask would be a poor choice, because the only marking on that flask would be 25 mL and measuring 10.0 mL sample of Fe^{2+} would not be possible.

g) $7.531\,g\ Fe_2O_3 \left| \frac{1\ mol\ Fe_2SO_3}{159.7\,g\ Fe_2SO_3} \right. = 0.04716\ mol\ Fe_2O_3$

h) 100%

i) The calculated mass percent of Fe(s) ~~would~~ in the original sample would be lower because some of the mass would be found in FeO(s). This would reduce the actual mass percent of Fe(s) because there would be less mass found in Fe_2SO_3(s).

c) Fe^{3+} ions have less electrons than Fe^{2+}, therefore, having a higher positive charge. This higher positive charge will cause a stronger interaction with water molecules.

b)

GO ON TO THE NEXT PAGE.

PAGE FOR ANSWERING QUESTION 3

a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^4$

b) Both ions have the same nuclear charge, but the Fe^{+2} ion is larger because it has more electrons than the Fe^{+3} ion. Because it has fewer electrons, the electrons are pulled closer to the nucleus because of Fe^{+3}'s nuclear charge, which makes the atomic radius smaller.

c) Fe^{+3} react stronger because they have a greater charge than Fe^{+2}.

d) $5\,Fe^{+2}_{(aq)} \rightarrow 5\,Fe^{+3}_{(aq)} + 5e^-$

e) $[MnO_4^-] = \frac{0.0350}{1000\,mL} \times 17.48\,mL = 6.118 \times 10^{-4}$

At equivalence point, $[Fe^{+2}] = [MnO_4^-]$, so $\boxed{[Fe^{+2}] = 0.0350\,M}$

f) The 25 mL would be a bad choice because it is the least accurate in determining the volume of a solution. The graduated cylinder would be the best option.

g) $7.51\,g\ Fe_2O_3 \times \frac{1\,mole\ Fe_2O_3}{159.7\,g\ Fe_2O_3} = \boxed{4.716 \times 10^{-2}\,g\ Fe_2O_3}$

h) 3.2%

i) The calculated mass percent in the original sample would be the same, because the mass of Fe would still be present, just as FeO instead

as actual mass % Fe

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3I 1 of 1

a.)

b.) The Fe^{2+} ion has a larger atomic radius then that of the Fe^{+3} ion because the Fe^{2+} ion has a greater amount of electrons therefore requiring greater space for those to orbit.

c.) The Fe^{3+} ion is smaller, and according to Coulumbs law, the smaller the ion the greater the interaction

d.) $Fe^{2+}(aq) \longrightarrow -e + Fe^{3+}(aq)$

e.) $MV = MV$

$(0.0350\,M)(17.48\,mL) = M(10.0\,mL)$

$\boxed{0.0612\,M\ Fe^{2+}}$

f.) The 25 mL volumetric Flask would be a poor choice for delivering the volume of the Fe^{2+} solution because it is not very accurate and would cause error.

g.) $7.531\,g\ Fe_2O_3 \left| \frac{1\,mol\,Fe_2O_3}{159.7\,g} \right| \left| \frac{2\,mol\,Fe}{1\,mol\,Fe_2O_3} \right| = 0.09431\ mols\ Fe$

h.) 89 % Fe

i.) lower, molar mass is lower in FeO

GO ON TO THE NEXT PAGE.

3J 1 of 2

a) $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2$

b) The radius of Fe^{2+} is bigger than the radius of Fe^{3+} because when looking at the Fe^{2+} ion, you take away two electrons due to its oxidation, but when looking at the Fe^{3+} ion, you take away 3 electrons. Therefore, the Fe^{2+} ion has a larger ionic radius than Fe^{3+}.

c) Fe^{3+} ions interact more strongly with water molecules than Fe^{2+} because since Fe^{3+} has a smaller ionic radius, that means the force it has with water molecules than that of Fe^{2+}. Coulomb's law justifies that the smaller the ionic radius is, the stronger the force is.

d) Balanced equation:

$5\,Fe^{2+} - 1e^- \rightarrow 5\,Fe^{3+}$ Oxidation = losing electrons

e) $0.01748\,L \cdot 0.0350\,M = 6.118 \times 10^{-4}\,mol$

$6.118 \times 10^{-4}\,mol / 0.010\,L = \boxed{0.0612\,M = [Fe^{2+}]}$

f) The 25 mL volumetric flask would be a poor choice to deliver the required volume of Fe^{2+} solution because it wouldn't display the Fe^{2+} solution very well; it would be difficult to obtain data from it.

g) $\frac{7.531\,g\ Fe_2O_3 \mid 1\,mol\ Fe_2O_3}{159.7\,g\ Fe_2O_3} = 0.0472\,mol\ Fe_2O_3$

ratio of Fe_2O_3 : Fe is 1 : 2

0.0472 mol / 2

* 0.0236 moles Fe produced *

h) $6.724\,g / 7.531\,g = 0.8928 \times 100$

* % by mass Fe = 89.3% *

ADDITIONAL PAGE FOR ANSWERING QUESTION 3

1) The calculated mass % of Fe in the original sample would be higher than the actual mass % of Fe because some of the mass would go to FeO, which means that the actual mass % would be less than the original.

AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
2018 AP CHEMISTRY

Question 3

Sample Identifier: 3A
Score: 10

- (a) States that the correct electron configuration of the Fe^{2+} cation- 1 point
- (b) Explained that Fe^{2+} has one more electron than Fe^{3+} and therefore more electron-electron repulsion to expand ionic radius- 1 point
- (c) Wrote that Fe^{3+} has a greater positive charge to attract the negative end of the polar water molecule and indicates that the smaller ionic radius allows a closer approach of the ion to the water molecule- 1 point
- (d) Extracted the oxidation half-reaction from the balanced redox reaction- 1 point
- (e) Calculated the correct number of moles of permanganate, used the stoichiometric ratio to find the number of moles of iron(II), and divided by the volume in liters to determine molarity- 2 points
- (f) Explained that the volumetric flask has a demarcation only at 25 mL and not at 10 mL- 1 point
- (g) Calculated moles of iron (within 1 significant figure of the correct 4 significant figures is acceptable) - 1 point
- (h) Calculated the mass percent of iron in sample of iron powder containing an inert impurity- 1 point
- (i) Determined and explained that the hypothetical situation of incomplete oxidation of the iron powder would result in a lower mass percent of iron in the original sample- 1 point

Sample Identifier: 3B
Score: 9

- (a) Wrote the correct electron configuration of the Fe^{2+} cation- 1 point
- (b) Neglected the repulsive forces between electrons in the species with more electrons- 0 point
- (c) Wrote that Fe^{3+} has a greater positive charge to attract the negative end of the polar water molecule-1 point
- (d) Wrote the oxidation half-reaction from the balanced redox reaction (unusual placement of negative sign over electron disregarded)- 1 point
- (e) Calculated the correct number of moles of permanganate, used the stoichiometric ratio to find the number of moles of iron(II), and divided by the volume in liters to determine molarity (*M*)-2 points
- (f) Explained that the 25 mL volumetric flask can measure only at 25 mL and no other volume-1 point
- (g) Calculated moles of iron (four significant figures is correct)- 1 point
- (h) Calculated the mass percent of iron in sample of iron powder containing an inert impurity- 1 point
- (i) Stated the calculated mass percentage would be lower with an acceptable explanation- 1 point

Sample Identifier: 3C
Score: 8

- (a) Wrote the correct core form of the electron configuration of the Fe^{2+} cation- 1 point
- (b) Explained that Fe^{2+} has one more electron than Fe^{3+} and therefore more electron-electron repulsion to expand ionic radius-- 1 point
- (c) Wrote that Fe^{3+} has a greater positive charge to interact with water (included substitution into Coulomb's Law)-1 point
- (d) Identified the correct oxidation half-reaction- 1 point
- (e) Calculated the correct number of moles of permanganate, used the stoichiometric ratio to find the number of moles of iron(II), and divided by the volume in liters to determine molarity (*M*)- 2 points
- (f) Incorrectly stated that the 25 mL volumetric flask will be too large to accurately measure 10 mL- 0 point
- (g) Calculated moles of iron (four significant figures is correct)- 1 point
- (h) Calculated the mass percent of iron in sample of iron powder containing an inert impurity- 1 point

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(i) Incorrectly states that the calculated mass percentage would be higher- 0 point

Sample Identifier: 3D
Score: 7

- (a) Wrote the correct core form electron configuration of the Fe^{2+} cation- 1 point
- (b) Does not explain electron repulsion in iron(II) as reason for larger radius- 0 point
- (c) Wrote that Fe^{3+} has a greater positive charge to interact with water molecules-1 point
- (d) Identified the correct oxidation half-reaction- 1 point
- (e) Calculated the correct number of moles of permanganate anion, used the stoichiometric ratio to find the number of moles of iron(II) cation, and divided by the volume in liters to determine molarity (*M*)- 2 points
- (f) Volumetric flasks are not used "primarily for transferring gases" - 0 point
- (g) Mass of iron(III) oxide was correctly converted to moles Fe (within ± 1 SF)- 1 point
- (h) Took the number of moles of Fe from (g), converted to mass Fe, and compared to the mass of the impure iron powder to express as mass percent 1 point
- (i) Inadequate explanation for percent mass in oxidized sample (FeO actually contains more moles per mass of Fe than does Fe_2O_3)- 0 point

Sample Identifier: 3E
Score: 6

- (a) Incorrectly removes 3*d* electrons rather than valence 4*s* electrons- 0 point
- (b) Neglects repulsion of more electrons in iron(II)- 0 point
- (c) Wrote that Fe^{3+} has a stronger net charge to interact with negative species like the polar water molecule-1 point
- (d) Identified the correct oxidation half-reaction- 1 point
- (e) Calculated the correct number of moles of permanganate anion, implicitly used the correct stoichiometric ratio, and divided by the volume in liters to determine molarity (*M*)-2 points
- (f) A volumetric flask does have one marking to indicate a pre-determined volume, in this case 25 mL- 0 point
- (g) Correctly calculated the number of moles of iron(III) oxide implicitly and the moles of iron-1 point
- (h) Took the number of moles of Fe from (g), converted to mass Fe, and compared to the mass of the impure iron powder to express as mass percent-1 point
- (i) Incorrect comparison of ratio of iron to oxygen in the oxidized sample- 0 point

Sample Identifier: 3F
Score: 5

- (a) Incorrectly removes two electrons from 3*d* rather than 4*s* and also adds 4*p* electrons- 0 point
- (b) Does not address electron repulsion to cause larger radius -0 point
- (c) Wrote that Fe^{3+} has a greater positive charge to attract the negative end of the polar water molecule-1 point
- (d) Identified the correct oxidation half-reaction- 1 point
- (e) Calculated the correct number of moles of permanganate anion, used the stoichiometric ratio to find the number of moles of iron(II) cation, and divided by the volume in liters to determine molarity (*M*)- 2 points
- (f) Does not explain why a volumetric flask marked for a measurement of 25 mL exactly of liquid only should not be selected to measure 10 mL, where no such marking exists- 0 point
- (g) Incorrect calculation of formula mass of iron(III) oxide- 0 point

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- (h) Incorrect calculation of moles of iron(III) oxide from (g) then used appropriately to find mass of Fe (although mislabeled "F"), then compared to mass of impure iron sample for consistent mass percent-1 point
- (i) Incorrectly selects "the same" for mass percent of iron in the incompletely oxidized sample- 0 point

Sample Identifier: 3G
Score: 4

- (a) Incorrectly removes electrons from 3*d* - 0 point
- (b) Is not addressed- 0 point
- (c) Wrote that Fe^{3+} has a greater positive charge to interact with water molecules-1 point
- (d) Identified the correct oxidation half-reaction- 1 point
- (e) Multiplied molarity of $KMnO_4$ by its volume in L and divided by the volume of iron(II) to find incorrect molarity of Fe^{2+} (stoichiometric ratio has not been applied) -1 point
- (f) Explained that the 25 mL volumetric flask can measure 25 mL only and no other volume- 1 point
- (g) Correct calculation of moles of iron(III) oxide but not moles of iron- 0 point
- (h) "Iron with inert impurity" cannot be 100% iron- 0 point
- (i) A new compound of iron, sulfur, and oxygen appears-0 point

Sample Identifier: 3H
Score: 3

- (a) Incorrectly removes electrons from 3*d* - 0 point
- (b) Does not address idea of electron repulsion to expand radius of ion- 0 point
- (c) Wrote that Fe^{3+} has a greater charge to interact with water molecules-1 point
- (d) Identified the correct oxidation half-reaction- 1 point
- (e) Multiplied molarity of $KMnO_4$ by its volume in L to find moles of $KMnO_4$ but neglects to determine correct molarity of iron(II)- 1 point
- (f) Does not indicate why the volumetric flask would be a poor choice when used at a different volume than the one demarcated- 0 point
- (g) Does not calculate moles of iron; correctly calculates moles of iron(III) oxide and calls it grams instead- 0 point
- (h) No work shown to support incorrect mass percentage calculation- 0 point
- (i) Selects "the same" mass percent -0 point

Sample Identifier: 3I
Score: 2

- (a) not addressed- 0 point
- (b) Incorrectly attributes larger atomic radius to greater number of electrons- 0 point
- (c) Incorrect interpretation of Coulomb's Law- 0 point
- (d) Incorrect form of equation seems to subtract electron- 0 point
- (e)) Multiplied molarity of $KMnO_4$ by its volume in L to find millimoles of $KMnO_4$, divided by the volume of the iron(II) solution but neglected the mole ratio from the balanced equation -1 point
- (f) Does not refer to idea of lack of marking at 10 mL on a 25-mL volumetric flask- 0 point
- (g) Correct calculation of moles of iron; correct number of significant figures- 1 point
- (h) Incorrect answer with no supporting work- 0 point
- (i) Correct prediction of lower mass percent but justification is not adequate- 0 point

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AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
2018 AP CHEMISTRY

Sample Identifier: 3J
Score: 1

- (a) All six 3*d* electrons have been lost- 0 point
- (b) Does not address idea of electron repulsion to expand radius of ion- 0 point
- (c) Does not address distance between iron(II) cation and oxygen end of water molecule- 0 point
- (d) Incorrect equation, electron subtracted from reactant, not balanced- 0 point
- (e) Multiplied molarity of $KMnO_4$ by its volume in L to find moles of $KMnO_4$, divided by the volume of the iron(II) solution but neglected the mole ratio from the balanced equation-1 point
- (f) Answer does not refer to marking on volumetric flask- 0 point
- (g) Calculation for number of moles of iron is incorrect as the mole ratio is inverted -0 point
- (h) Does not consider that some of the mass of the Fe in contaminated sample is something else- 0 point
- (i) "Higher" mass percent of iron is incorrect- 0 point

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Sulfur atom = ◯ Carbon atom = ● Oxygen atom = ○

Compound	Molecular Structure	Boiling Point at 1 atm (K)
CS_2		319
COS		223

4. The table above gives the molecular structures and boiling points for the compounds CS_2 and COS.

   (a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

   (b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

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Question 4

Sulfur atom = Carbon atom = Oxygen atom =

Compound	Molecular Structure	Boiling Point at 1 atm (K)
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COS		223

The table above gives the molecular structures and boiling points for the compounds CS_2 and COS.

(a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

CS_2 has only London dispersion forces, while COS has London dispersion forces and dipole-dipole forces. The London dispersion forces in CS_2 are stronger than the combination of London dispersion forces and dipole-dipole forces in COS.	1 point is earned for correctly identifying all of the intermolecular forces in **both** molecules. 1 point is earned for a valid explanation.

(b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

$10.0 \text{ g } CS_2 \times \frac{1 \text{ mol } CS_2}{76.13 \text{ g } CS_2} = 0.131 \text{ mol } CS_2$ $P = \frac{nRT}{V} = \frac{(0.131 \text{ mol})(0.08206 \text{ L atm mol}^{-1}\text{K}^{-1})(325 \text{ K})}{5.0 \text{ L}}$ $= 0.70 \text{ atm}$	1 point is earned for the correct number of moles of CS_2. 1 point is earned for the correct calculation of pressure with appropriate units.

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Sulfur atom = ◎ Carbon atom = ● Oxygen atom = ○

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(b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

4a. CS_2 has dispersion forces only and COS has dispersion forces and dipole-dipole forces. However, CS_2 has more electrons, making it more polarizable than COS. The strength of the dispersion forces in CS_2 must be stronger than the dispersion and dipole-dipole forces in COS.

b. $PV = nRT$

$(P)(5.0\ L) = (0.131)(0.0821)(325\ K)$

$P = 0.699\ atm$

$10.0\ g \left| \frac{1\ mol\ CS_2}{76.13\ g} \right.$

$0.131\ mol\ CS_2$

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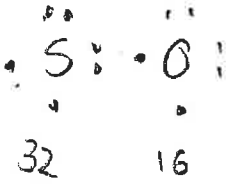
Sulfur atom = ◎ Carbon atom = ● Oxygen atom = ○



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(a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

(b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

a) CS_2 has one more S atom than COS and the S atom has electrons further from the nucleus increasing polarizability and the london dispersion forces because there are more electrons as a whole, therefore there are more inter molecular forces between molecules of CS_2 and it has a higher boiling point.

b) $n_{(CS_2)} = \frac{10\,g}{(12 + (2 \times 32.06))} = \frac{10\,g}{76.12\,g} = 0.1314$ mols

$CS_2(l) \rightarrow CS_2(g)$ not ⊠ $CS_2\,l \rightarrow C^{4+}_{mol} + 2S$

$PV = nRT$

$P = \frac{nRT}{V} = \frac{(0.1314\,mol)\left(0.08206\,\frac{L\,atm}{mol\,K}\right)(325\,K)}{5\,L}$

$= 0.700722$ atm

$= 0.701$ atm

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Sulfur atom = ◎ Carbon atom = ● Oxygen atom = ○

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a. CS_2 has much larger LDF forces than COS due to being a larger molecule with far more e⁻.

b. $PV = nRT \rightarrow P = \frac{.12m(.08206 \frac{L\,atm}{mol\,K}(325K)}{5L}$ $10g(\frac{1}{64}) = .12m$

$P = .64$ atm

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COS		223

4. The table above gives the molecular structures and boiling points for the compounds CS_2 and COS.

   (a) In terms of the types and relative strengths of all the intermolecular forces in each compound, explain why the boiling point of $CS_2(l)$ is higher than that of $COS(l)$.

   (b) A 10.0 g sample of $CS_2(l)$ is put in an evacuated 5.0 L rigid container. The container is sealed and heated to 325 K, at which temperature all of the $CS_2(l)$ has vaporized. What is the pressure in the container once all of the $CS_2(l)$ has vaporized?

4a) Boiling Point of CS_2 is higher because it has 2 strong C-S bonds making it harder to melt, while COS has a C-O bond making it weaker

4b) $PV = nRT$

$$P(5L) = \left(10g \times \frac{1mol}{76.13g}\right)(8.3145 mol^{-1}K^{-})(325K)$$

$0.1314\ mol$

$$\frac{P(5L)}{.005} = \frac{354.93}{.005} \qquad P = 70.99 atm$$

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AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
2018 AP CHEMISTRY

Question 4

Sample Identifier: 4A
Score: 4

- (a) This response correctly identifies the intermolecular forces (IMF) for both. This earned 1 point.
- (a) This response correctly stated that the London dispersion forces (LDF) in CS_2 are greater than the IMF in COS. This earned 1 point.
- (b) There is the correct number of moles. This earned 1 point.
- (b) There is the correct pressure with units and work is shown. This earned 1 point.

Sample Identifier: 4B
Score: 3

- (a) This response only identifies the LDF in CS_2. This did not earn the point.
- (a) This response correctly stated that the London dispersion forces (LDF) in CS_2 are greater than the IMF in COS. This earned 1 point.
- (b) There is the correct number of moles. This earned 1 point.
- (b) There is the correct pressure with units and work is shown. This earned 1 point.

Sample Identifier: 4C
Score: 2

- (a) This response only identifies the LDF in CS_2. This did not earn the point
- (a) This response correctly stated that the London dispersion forces (LDF) in CS_2 are greater than the IMF in COS. This earned 1 point.
- (b) There is an incorrect number of moles. This did not earn the point.
- (b) The pressure is correctly calculated with the wrong number of moles and units and work is shown. This earned 1 point.

Sample Identifier: 4D
Score: 1

- (a)No IMF are identified, this does not earn the point.
- (a)This response does not state that the London dispersion forces (LDF) in CS_2 are greater than the IMF in COS. This did not earn the point.
- (b) There is the correct number of moles. This earned 1 point.
- (b) The pressure is reported with units that are not correct for the value of "R" that was used in the calculation. This did not earn the point.

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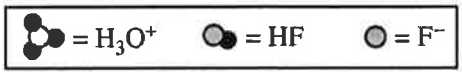
$$HF(aq) + H_2O(l) \rightleftarrows F^-(aq) + H_3O^+(aq)$$

5. The ionization of HF(aq) in water is represented by the equation above. In a 0.0350 M HF(aq) solution, the percent ionization of HF is 13.0 percent.

   (a) Two particulate representations of the ionization of HF molecules in the 0.0350 M HF(aq) solution are shown below in Figure 1 and Figure 2. Water molecules are not shown. Explain why the representation of the ionization of HF molecules in water in Figure 1 is more accurate than the representation in Figure 2. (The key below identifies the particles in the representations.)



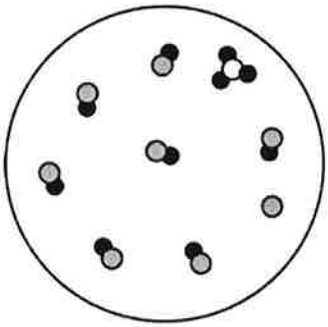


Figure 1

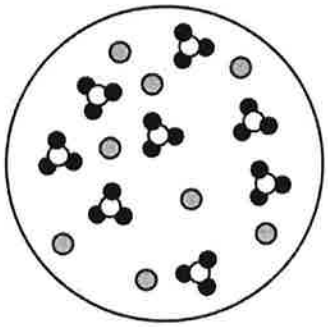


Figure 2

   (b) Use the percent ionization data above to calculate the value of K_a for HF.

   (c) If 50.0 mL of distilled water is added to 50.0 mL of 0.035 M HF(aq), will the percent ionization of HF(aq) in the solution increase, decrease, or remain the same? Justify your answer with an explanation or calculation.

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Question 5

$$HF(aq) + H_2O(l) \rightleftarrows F^-(aq) + H_3O^+(aq)$$

The ionization of $HF(aq)$ in water is represented by the equation above. In a 0.0350 M $HF(aq)$ solution, the percent ionization of HF is 13.0 percent.

(a) Two particulate representations of the ionization of HF molecules in the 0.0350 M $HF(aq)$ solution are shown below in Figure 1 and Figure 2. Water molecules are not shown. Explain why the representation of the ionization of HF molecules in water in Figure 1 is more accurate than the representation in Figure 2. (The key below identifies the particles in the representations.)

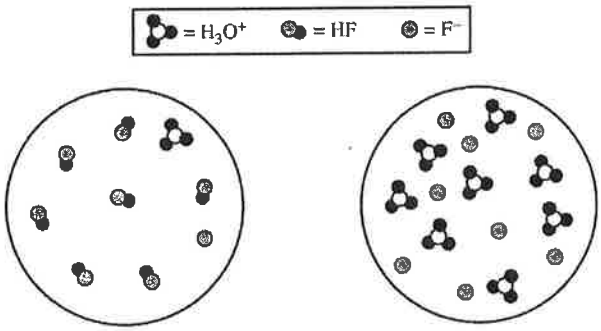

Figure 1 Figure 2

HF is a weak acid and is only partially ionized. This fact is consistent with Figure 1, which shows that one out of eight (~13%) HF molecules is ionized (to form one H_3O^+ and one F^-). OR Figure 2 cannot represent HF because it represents 100% ionization of the acid.	1 point is earned for a valid explanation.

(b) Use the percent ionization data above to calculate the value of K_a for HF.

Assume that $[H_3O^+] = [F^-]$ in $HF(aq)$. $\frac{[H_3O^+]}{0.0350\ M} = 0.130 \Rightarrow [H_3O^+] = 0.00455\ M$ $HF(aq) + H_2O(l) \rightleftarrows F^-(aq) + H_3O^+(aq)$ I 0.0350 0 ~0 C −0.00455 +0.00455 +0.00455 E 0.0304 0.00455 0.00455 $K_a = \frac{[H_3O^+][F^-]}{[HF]} = \frac{(0.00455)^2}{(0.0304)} = 6.81 \times 10^{-4}$	1 point is earned for the correct calculation of $[H_3O^+]$. 1 point is earned for a value of K_a consistent with the calculated value of $[H_3O^+]$.

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Question 5 (continued)

(c) If 50.0 mL of distilled water is added to 50.0 mL of 0.035 *M* HF(*aq*), will the percent ionization of HF(*aq*) in the solution increase, decrease, or remain the same? Justify your answer with an explanation or calculation.

The percent ionization of HF in the solution would increase. Doubling the volume of the solution decreases the initial concentration of each species by one-half. Therefore $Q = \frac{(\frac{1}{2}[H_3O^+]_i)(\frac{1}{2}[F^-]_i)}{\frac{1}{2}[HF]_i} = \frac{1}{2}K_a \Rightarrow Q < K_a$, consequently the equilibrium position will shift toward the products and increase the percent ionization. **OR** New volume = twice original volume, thus new $[HF]_i = \frac{0.035}{2} = 0.0175\ M$ $K_a = \frac{[H_3O^+][F^-]}{[HF]} = 6.81 \times 10^{-4}$ (value from part (b)) Let $[H_3O^+] = [F^-] = x$ Then $6.81 \times 10^{-4} = \frac{(x)(x)}{(0.0175 - x)} \approx \frac{x^2}{(0.0175)} \Rightarrow x \approx 0.00345\ M$ Percent ionization $= \frac{0.00345\ M}{0.0175\ M} \times 100 = 20.\%$ $20.\% > 13.0\%$, therefore the percent ionization increases.	1 point is earned for a correct answer and a valid explanation or calculation.

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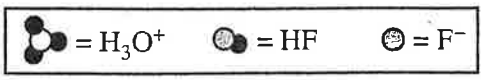
5A 1 of 2

$$HF(aq) + H_2O(l) \rightleftarrows F^-(aq) + H_3O^+(aq)$$

5. The ionization of $HF(aq)$ in water is represented by the equation above. In a 0.0350 M $HF(aq)$ solution, the percent ionization of HF is 13.0 percent.

(a) Two particulate representations of the ionization of HF molecules in the 0.0350 M $HF(aq)$ solution are shown below in Figure 1 and Figure 2. Water molecules are not shown. Explain why the representation of the ionization of HF molecules in water in Figure 1 is more accurate than the representation in Figure 2. (The key below identifies the particles in the representations.)



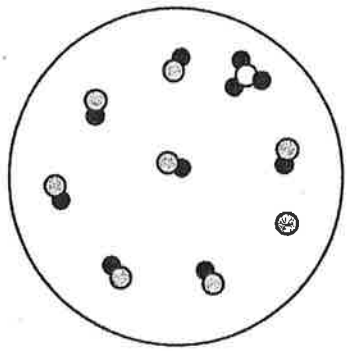


Figure 1

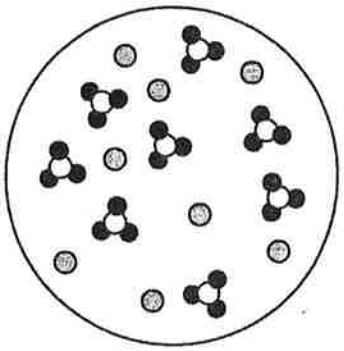


Figure 2

(b) Use the percent ionization data above to calculate the value of K_a for HF.

(c) If 50.0 mL of distilled water is added to 50.0 mL of 0.035 M $HF(aq)$, will the percent ionization of $HF(aq)$ in the solution increase, decrease, or remain the same? Justify your answer with an explanation or calculation.

a) this is a weak acid, so few, definately not all of the HF is split and forms H_3O^+ as shown in figure 2. Instead, most don't, as shown in figure 1.

b) $HF + H_2O \rightleftharpoons F^- + H_3O^+$ $\quad .0350M \cdot .130 = .00455\,M$

1.	.0350M	0	0
C	-.00455M	+.00455M	+.00455M
E	.0305M	.00455M	.00455 M

$$K_a = \frac{[.00455]^2}{.0305} = \boxed{6.79 \times 10^{-4}}$$

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ADDITIONAL PAGE FOR ANSWERING QUESTION 5

c) $HF + H_2O \rightleftharpoons F^- + H_3O^+$

$M_1V_1 = M_2V_2$

$.035(50.0) = x(100.0)$

$x = .0175\ M$

	HF	H_2O	F^-	H_3O^+
I	.018 M		0	0
C	$-x$		$+x$	$+x$
E	$.018 - x$		x	x

$6.79 \times 10^{-4} = \frac{x^2}{.018 - x}$

$x = .0032\ M$

$\frac{.0032}{.018} \times 100\% = 18\%$

increases $\rightarrow 13\%$

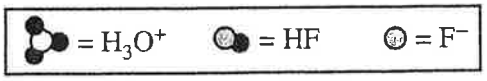
GO ON TO THE NEXT PAGE.

5B, 1 of 2

$$HF(aq) + H_2O(l) \rightleftarrows F^-(aq) + H_3O^+(aq)$$

5. The ionization of HF(aq) in water is represented by the equation above. In a 0.0350 M HF(aq) solution, the percent ionization of HF is 13.0 percent.

(a) Two particulate representations of the ionization of HF molecules in the 0.0350 M HF(aq) solution are shown below in Figure 1 and Figure 2. Water molecules are not shown. Explain why the representation of the ionization of HF molecules in water in Figure 1 is more accurate than the representation in Figure 2. (The key below identifies the particles in the representations.)



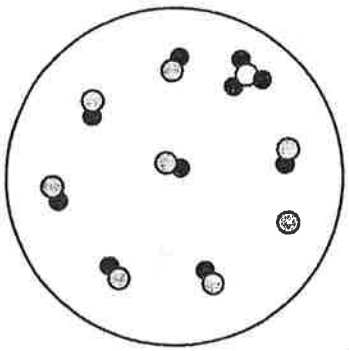


Figure 1

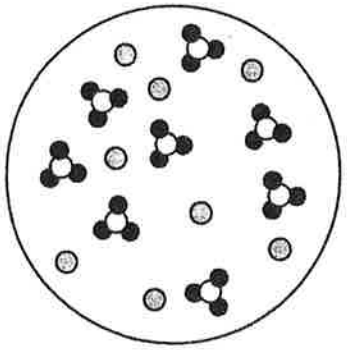


Figure 2

(b) Use the percent ionization data above to calculate the value of K_a for HF.

(c) If 50.0 mL of distilled water is added to 50.0 mL of 0.035 M HF(aq), will the percent ionization of HF(aq) in the solution increase, decrease, or remain the same? Justify your answer with an explanation or calculation.

a.) When showing ionization with water, it is important to remember that only 13% of the HF was ionized. In Figure 2, all was ionized, making the representation non suitable.

b) $HF + H_2O \rightleftharpoons F^- + H_3O^+$ $\quad 13\% = 0.13 \cdot 100$

I	0.0350 M	0	0
C	0.00455	0.00455	0.00455
E	0.03045	0.00455	0.00455

$0.13 \times (0.0350) = 0.00455$

$K_a = \frac{[F^-][H_3O^+]}{[HF]} = \frac{[0.00455]^2}{[0.03045]} = 6.8 \times 10^{-4}$

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GO ON TO THE NEXT PAGE.

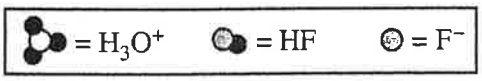
C.) The percent ionization of HF would remain the same. This is due to the proportions for in the K_a equation having to stay constant, in terms of molarity, due to K_a being constant for the reaction

5C 1 of 2

$$HF(aq) + H_2O(l) \rightleftarrows F^-(aq) + H_3O^+(aq)$$

5. The ionization of $HF(aq)$ in water is represented by the equation above. In a 0.0350 M $HF(aq)$ solution, the percent ionization of HF is 13.0 percent.

   (a) Two particulate representations of the ionization of HF molecules in the 0.0350 M $HF(aq)$ solution are shown below in Figure 1 and Figure 2. Water molecules are not shown. Explain why the representation of the ionization of HF molecules in water in Figure 1 is more accurate than the representation in Figure 2. (The key below identifies the particles in the representations.)



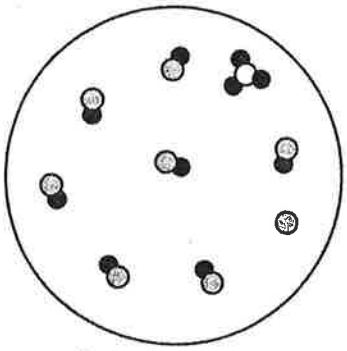


Figure 1

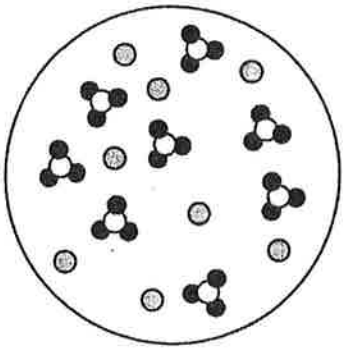


Figure 2

   (b) Use the percent ionization data above to calculate the value of K_a for HF.

   (c) If 50.0 mL of distilled water is added to 50.0 mL of 0.035 M $HF(aq)$, will the percent ionization of $HF(aq)$ in the solution increase, decrease, or remain the same? Justify your answer with an explanation or calculation.

a. Figure 1 is more accurate compared to Figure 2 because it demonstrates how the HF molecules are not completely ionized. Whereas Figure 2 shows it completely ionized with no remaing HF molecules.

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b. ~~HF → F⁻ + H⁺~~

	HF	F^-	H^+
I	.035		
C			
E			

$.035 \times .13 = .00455$

$K = \frac{[F^-][H^+]}{[HF]}$

$K = \frac{[.00455][.00455]}{[.035]}$

$K = 5.92 \times 10^{-4}$

c. The percent ionization will increase if 50 mL of water is added to 50 mL of HF. This is because the amount of HF molecules will increase but the water molecules do not interfere.

GO ON TO THE NEXT PAGE.

$$HF(aq) + H_2O(l) \rightleftarrows F^-(aq) + H_3O^+(aq)$$

5. The ionization of HF(*aq*) in water is represented by the equation above. In a 0.0350 *M* HF(*aq*) solution, the percent ionization of HF is 13.0 percent.

(a) Two particulate representations of the ionization of HF molecules in the 0.0350 *M* HF(*aq*) solution are shown below in Figure 1 and Figure 2. Water molecules are not shown. Explain why the representation of the ionization of HF molecules in water in Figure 1 is more accurate than the representation in Figure 2. (The key below identifies the particles in the representations.)

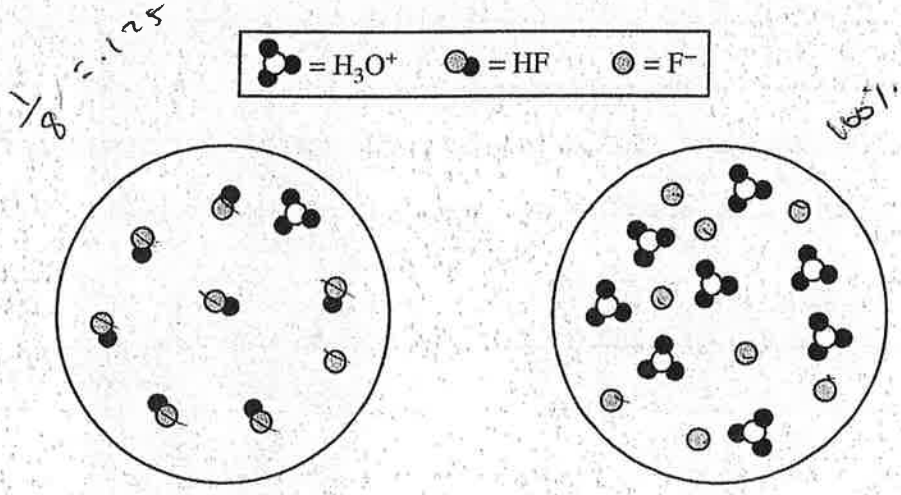

Figure 1

Figure 2

(b) Use the percent ionization data above to calculate the value of K_a for HF.

(c) If 50.0 mL of distilled water is added to 50.0 mL of 0.035 *M* HF(*aq*), will the percent ionization of HF(*aq*) in the solution increase, decrease, or remain the same? Justify your answer with an explanation or calculation.

a) In figure 1, only one HF molecule out of 8 is ionized, giving that HF about a 13% ionization (12.5%) while in figure 2, 8 out of 8 molecules are ionized which means 100% ionization and that is not accurate since HF is a weak acid and does not ionize completely.

b) $K_a = 0.143$ $K_a = \frac{[F^-]}{[HF]} = \frac{[I]}{[8]}$ $K_a = .143$

c) The percent ionization will increase since HF is a weak acid, the more water there is, the more likely a chance of that one of

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5D 2 of 2

the HF molecules willionize.

AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
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Question 5

Sample Identifier: 5A
Score: 4

- Response correctly compared the complete ionization in Figure 2 to the incomplete ionization in Figure 1 for 1 point.
- Response includes the correct calculation of $[H_3O^+]$ for 1 point.
- The calculated $[H_3O^+]$ and the correct [HF] are used correctly in the equilibrium expression to calculate the correct value of K_a for 1 point.
- Response correctly used a Q calculation to explain a correct answer for 1 point.

Sample Identifier: 5B
Score: 3

- Response correctly states that in Figure 2 all of the $HF(aq)$ is ionized for 1 point.
- Correct calculation of $[H_3O^+]$ for 1 point.
- The calculated $[H_3O^+]$ and the correct [HF] are used correctly in the equilibrium expression to calculate the correct value of K_a for 1 point.
- Incorrect answer and incorrect explanation for 0 point.

Sample Identifier: 5C
Score: 2

- Correct comparison of complete ionization represented in Figure 2 to the incomplete ionization represented in Figure 1 for 1 point.
- Response includes the correct calculation of $[H_3O^+]$ for 1 point.
- The calculated $[H_3O^+]$ is used correctly in the equilibrium expression, but an incorrect value for [HF] is used in the equilibrium expression which led to an incorrect value of K_a for 0 point.
- A correct answer but an incorrect explanation for 0 point.

Sample Identifier: 5D
Score: 1

- Response correctly states that there are more HF and less H_3O^+ and F^- represented in Figure 1 for 1 point.
- Response does not include a correct calculation of the $[H_3O^+]$ for 0 point.
- Response does not include a correct calculation of K_a for 0 point.
- Response makes an incorrect statement that the concentrations increase for 0 point.

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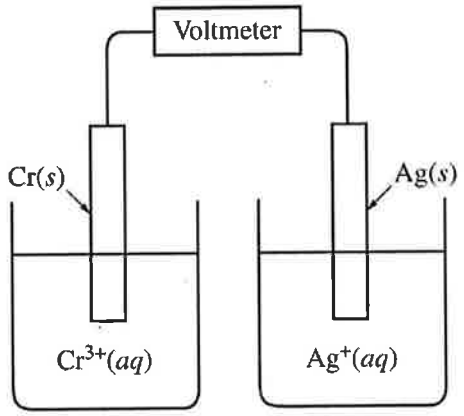

6. A student sets up a galvanic cell at 298 K that has an electrode of $Ag(s)$ immersed in a 1.0 M solution of $Ag^{+}(aq)$ and an electrode of $Cr(s)$ immersed in a 1.0 M solution of $Cr^{3+}(aq)$, as shown in the diagram above.

   (a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\ e^{-} \rightarrow Cr(s)$	?

   (b) The student adds the missing component to the cell and measures E°_{cell} to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

      (i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\ e^{-} \rightarrow Cr(s)$.

      (ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

      (iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

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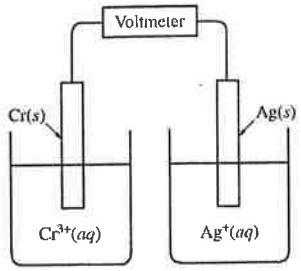
Question 6



A student sets up a galvanic cell at 298 K that has an electrode of $Ag(s)$ immersed in a 1.0 M solution of $Ag^{+}(aq)$ and an electrode of $Cr(s)$ immersed in a 1.0 M solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

The salt bridge is missing. The salt bridge allows for the migration of ions to maintain charge balance in each half-cell.	1 point is earned for the correct answer and a valid explanation.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\ e^{-} \rightarrow Cr(s)$	?

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\ e^{-} \rightarrow Cr(s)$.

$E°_{cell} = E°_{red}(\text{cathode}) - E°_{red}(\text{anode})$ $+1.54\ \text{V} = +0.80\ \text{V} - x$ $x = +0.80\ \text{V} - (+1.54\ \text{V}) = -0.74\ \text{V}$	1 point is earned for a correct calculation of $E°_{red}$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

$3\ Ag^{+}(aq) + Cr(s) \rightarrow 3\ Ag(s) + Cr^{3+}(aq)$	1 point is earned for the correctly balanced equation.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

$\Delta G° = -nFE° = -\left(\frac{3\ \text{mol}\ e^{-}}{1\ \text{mol}_{rxn}}\right)\left(96{,}485\frac{\text{C}}{\text{mol}\ e^{-}}\right)\left(1.54\ \frac{\text{J}}{\text{C}}\right)$ $= -4.46 \times 10^{5}\ \text{J/mol}_{rxn}$	1 point is earned for the correct calculation of the value of $\Delta G°$.

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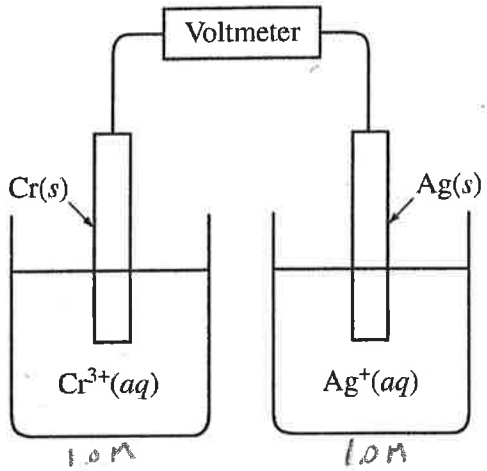

6. A student sets up a galvanic cell at 298 K that has an electrode of Ag(s) immersed in a 1.0 M solution of $Ag^+(aq)$ and an electrode of Cr(s) immersed in a 1.0 M solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

$\Delta G = -3(96485)(1.54)$ RED

OX

Half-Reaction	$E°$ (V)
$Ag^+(aq) + e^- \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\,e^- \rightarrow Cr(s)$	?

$x + .8 = 1.54$

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^+ ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\,e^- \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

a. There is no salt bridge in the cell. The salt bridge transports ions between the two solutions. Without it there are no half reactions happening, resulting in zero voltage.

b. i. $E° = -0.74$ V

ii. $3\,Ag^+_{(aq)} + 1\,Cr_{(s)} \rightarrow 3\,Ag_{(s)} + 1\,Cr^{+3}_{(aq)}$

iii. $\Delta G = -445760.7$ J/mol rxn

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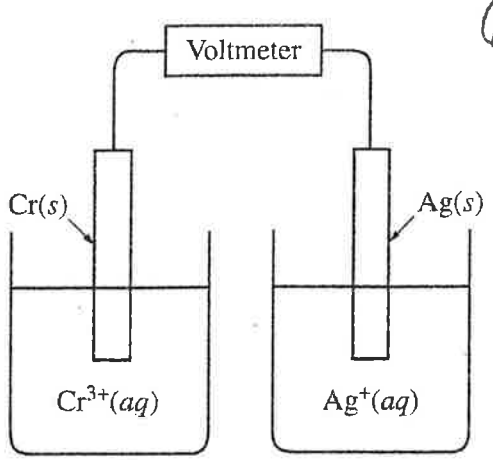
6B 1 of 1



6. A student sets up a galvanic cell at 298 K that has an electrode of Ag(s) immersed in a 1.0 M solution of $Ag^{+}(aq)$ and an electrode of Cr(s) immersed in a 1.0 M solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

$3(Ag \rightarrow Ag^{+} + e^{-})$

$Cr^{3+} + 3e^{-} \rightarrow Cr(s)$

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$	?

LEO
GER

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

a.) The student is missing the salt bridge. This is needed to allow the cations and anions flow freely.

b.) i. $+1.54 = +0.80 + x$

$0.74 = x$

$-0.74\ V = E°$

ii. $3Ag_{(s)} + Cr^{3+}_{(aq)} \rightarrow 3Ag^{+}_{(aq)} + Cr_{(s)}$

iii. $\Delta G° = -nFE°$

$\Delta G° = -3e^{-}\text{ mole} \left(\frac{96485\,C}{1\text{ mole } e^{-}}\right)(+1.54\,V)$

$\Delta G° = -445760.7\,J = -4.46 \times 10^{5}\ J/mol_{rxn}$

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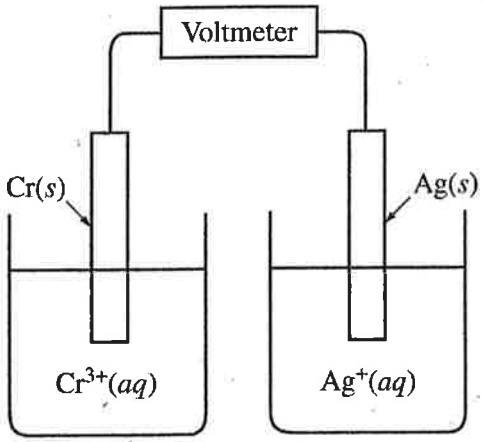
6C 1 of 2



6. A student sets up a galvanic cell at 298 K that has an electrode of Ag(*s*) immersed in a 1.0 *M* solution of $Ag^{+}(aq)$ and an electrode of Cr(*s*) immersed in a 1.0 *M* solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$	?

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

(a) The missing component is the salt bridge. Its importance in maintaining a nonzero voltage is that it makes sure that the all the electrons don't completely go from the anode to cathode. It maintains species in both electrodes which will allow the continual transfer of electrons instead of everything moving to the cathode. If there was no salt bridge all the electrons would just go to the cathode and there would be no transfer to measure at all.

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6C 2 of 2

(b) (i) $E°_{cell} = 1.54\ V$

$1.54\ V = (0.80\ V) + (-x\ V)$

$x = -0.74\ V$

(ii) $3Ag^{+}(aq) + Cr(s) \rightarrow 3Ag(s) + Cr^{3+}(aq)$

(iii) $\Delta G = -nFE$

$\Delta G = -(6\ mol\ e^-)(96485\ \frac{C}{mole^-})(1.54\ V)$

$\Delta G = -8.92 \times 10^5\ J/mol$

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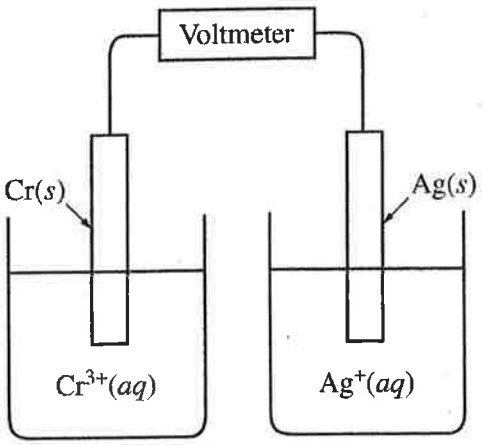
6D 1 of 1



6. A student sets up a galvanic cell at 298 K that has an electrode of $Ag(s)$ immersed in a 1.0 M solution of $Ag^{+}(aq)$ and an electrode of $Cr(s)$ immersed in a 1.0 M solution of $Cr^{3+}(aq)$, as shown in the diagram above.

(a) The student measures the voltage of the cell shown above and discovers that it is zero. Identify the missing component of the cell, and explain its importance for obtaining a nonzero voltage.

Half-Reaction	$E°$ (V)
$Ag^{+}(aq) + e^{-} \rightarrow Ag(s)$	+ 0.80
$Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$	?

(b) The student adds the missing component to the cell and measures $E°_{cell}$ to be +1.54 V. As the cell operates, Ag^{+} ions are reduced. Use this information and the information in the table above to do the following.

(i) Calculate the value of $E°$ for the half-reaction $Cr^{3+}(aq) + 3\,e^{-} \rightarrow Cr(s)$.

(ii) Write the balanced net-ionic equation for the overall reaction that occurs as the cell operates.

(iii) Calculate the value of $\Delta G°$ for the overall cell reaction in J/mol_{rxn}.

a) a salt bridge, which transfers negative ions back into solution to keep the cell running

b) i) $1.54V = x - .8$ ii) $3Ag_{(s)} + Cr^{3+}_{(aq)} \rightarrow 3Ag^{+}_{(aq)} + Cr_{(s)}$

$E° = 2.34V$

iii) $\Delta G° = -nFE$

$\Delta G° = -(3)\left(\frac{1}{96485}\right)(1.54)$

$\Delta G° = -4.8 \times 10^{-5}$

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AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
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Question 6

Sample Identifier: 6A
Score: 4

- In part (a), the student correctly indicates that the salt bridge "transports" ions between the two solutions in the cell. 1 point was earned.
- In part (b, i), the student correctly calculates the value of $E^{o}_{red.}$ 1 point was earned.
- In part (b, ii), the student correctly balances the redox reaction, and 1 point was earned.
- In part (b, iii), the student correctly calculates the value of ΔG^{o}. The student's work is shown near the reduction table. 1 point was earned.

Sample Identifier: 6B
Score: 3

- In part (a), the student properly indicates that cations and anions "flow freely" in a salt bridge. 1 point was earned.
- In part (b, i), the student algebraically calculates the oxidation potential of the half-cell as 0.74 V, then properly deduces that the *reduction* potential is -0.74 V. 1 point was earned.
- In part (b, ii), the student misidentifies the oxidation and reduction half reactions, balancing the reaction for an electrolytic cell, rather than a galvanic cell. 0 points were earned.
- In part (b, iii), the student correctly calculates the value of ΔG^{o}. 1 point was earned.

Sample Identifier: 6C
Score: 2

- In part (a), the student confuses the role of ionic charge imbalance in the salt bridge with electron imbalance in the response, by citing the "continual transfer" of electrons. The student also suggests that "everything" is "moving to the cathode" without a salt bridge present, which is incorrect. 0 points were earned.
- In part (b, i), the student correctly calculates the value of $E^{o}_{red.}$ 1 point was earned.
- In part (b, ii), the student correctly balances the redox reaction, and 1 point was earned.
- In calculating ΔG^{o}, the student in part (b, iii) incorrectly assigns the number or electrons transferred as $n = 6$. 0 points were earned.

Sample Identifier: 6D
Score: 1

- In part (a), the student correctly indicates that ions are transferred "back into solution to keep the cell running," implying migration of ions in the cell. 1 point was earned.
- In part (b, i), the student makes an algebraic error and incorrectly calculates the value of $E^{o}_{red.}$ 0 points were earned.
- In part (b, ii), the student misidentifies the oxidation and reduction half reactions, balancing the reaction for an electrolytic, rather than a galvanic, cell. 0 points were earned.
- In part (b, iii), the student incorrectly uses the reciprocal of the Faraday constant in calculating ΔG^{o}. 0 points were earned.

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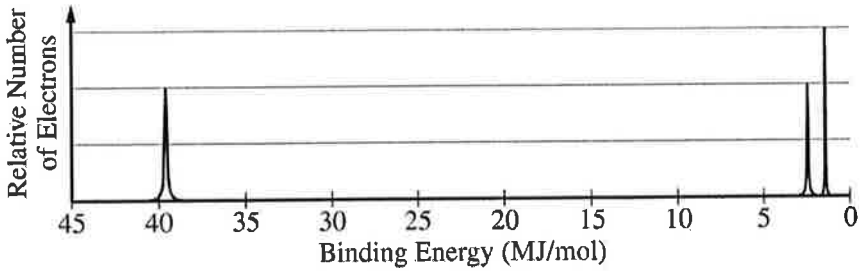

7. The complete photoelectron spectrum of an element is represented above.

   (a) Identify the element.

   A radioactive isotope of the element decays with a half-life of 10. minutes.

   (b) Calculate the value of the rate constant, k, for the radioactive decay. Include units with your answer.

   (c) If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

STOP

END OF EXAM

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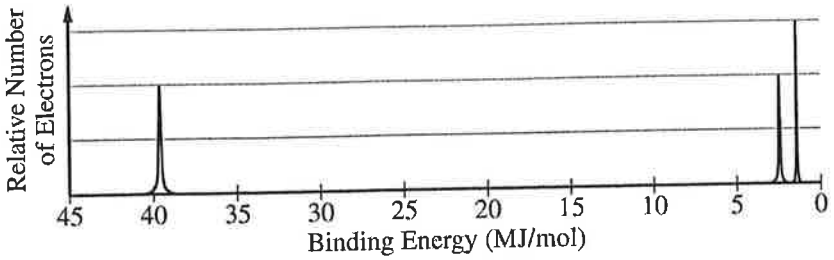
Question 7



The complete photoelectron spectrum of an element is represented above.

(a) Identify the element.

The element is nitrogen, N.	1 point is earned for correctly identifying the element.

A radioactive isotope of the element decays with a half-life of 10. minutes.

(b) Calculate the value of the rate constant, k, for the radioactive decay. Include units with your answer.

$k = \frac{0.693}{t_{1/2}} = \frac{0.693}{10.\text{ min}} = 0.069\text{ min}^{-1}$	1 point is earned for the correct numerical answer. 1 point is earned for the correct unit.

(c) If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

$64 \rightarrow 32 \rightarrow 16 \rightarrow 8 \rightarrow 4 \rightarrow 2 \rightarrow 1$ 6 half-lives are required. $6 \times 10.\text{ min} = 60.\text{ min}$ **OR** $\ln[A]_t - \ln[A]_0 = -kt$ $t = \frac{\ln(1) - \ln(64)}{-0.069\text{ min}^{-1}} = 60.\text{ min}$	1 point is earned for the correct answer and a valid method.

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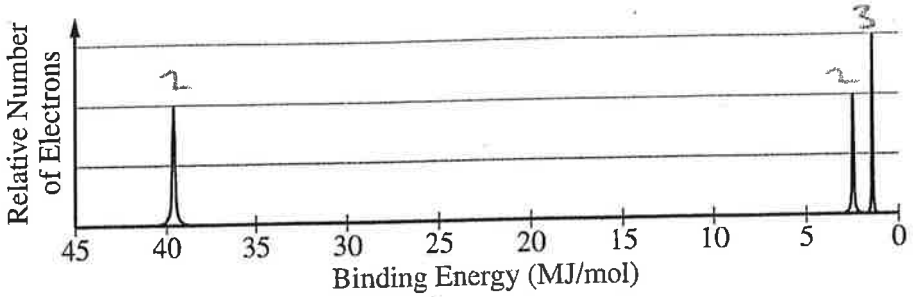

7. The complete photoelectron spectrum of an element is represented above.

(a) Identify the element.

A radioactive isotope of the element decays with a half-life of 10. minutes.

(b) Calculate the value of the rate constant, k, for the radioactive decay. Include units with your answer.

(c) If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

(a) The element is Nitrogen

(b) $t_{1/2} = \frac{0.693}{k}$

$k = \frac{0.693}{10.\text{min}} = \boxed{0.069\ \text{min}^{-1}}$

(c) $\ln[A]_t = \ln[A]_0 - kt$

$\ln(1) = \ln(64) - 0.069(t)$

$\boxed{t = 60.\ \text{min}}$

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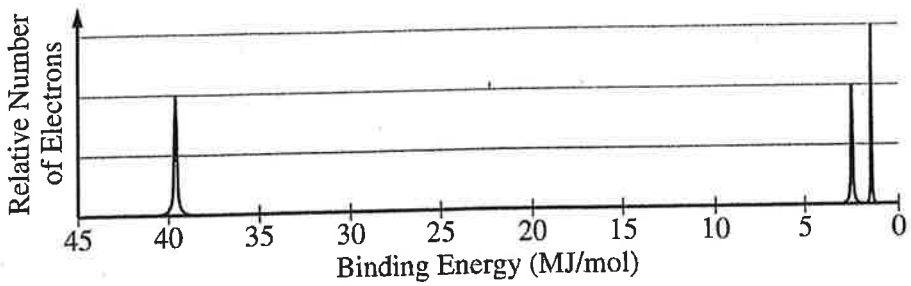

7. The complete photoelectron spectrum of an element is represented above.

(a) Identify the element.

A radioactive isotope of the element decays with a half-life of 10. minutes.

(b) Calculate the value of the rate constant, k, for the radioactive decay. Include units with your answer.

(c) If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

a) The element is Nitrogen

b) $t_{1/2} = \frac{0.693}{K}$

$K = \frac{0.693}{600.\,s}$

$K = .0012\ s^{-1}$

c) 64 atoms $\xrightarrow{10\,min}$ 32 atoms $\xrightarrow{10}$ 16 atoms $\xrightarrow{10}$ 8 atoms $\xrightarrow{10}$ 4 atoms $\xrightarrow{10}$ 2 atoms $\xrightarrow{10}$ 1 atom

5(10.) = 50. min

Approximately 50. minutes will pass until only one atom remains.

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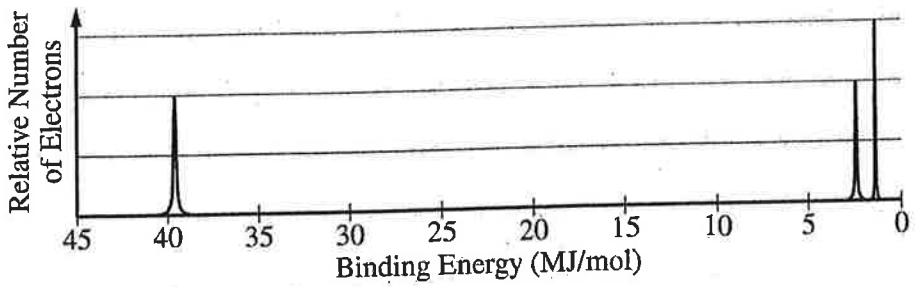
7C 1051



7. The complete photoelectron spectrum of an element is represented above.

(a) Identify the element.

A radioactive isotope of the element decays with a half-life of 10. minutes.

(b) Calculate the value of the rate constant, k, for the radioactive decay. Include units with your answer.

(c) If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

7) (a) N

(b) $10 \text{ mins} = \frac{0.693}{k}$

$k = 0.069 \text{ m/min}$

(c) 20 mins because if the half life is 10, double that is 20.

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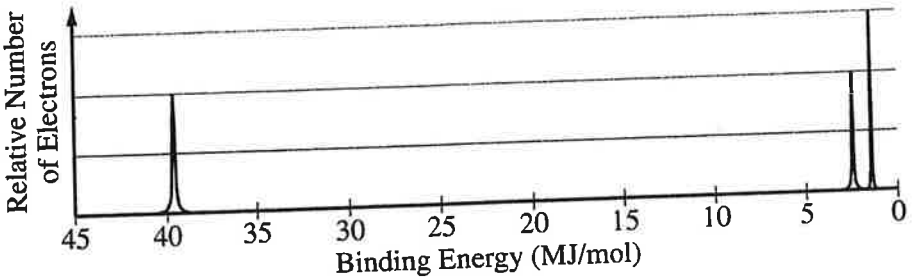

7. The complete photoelectron spectrum of an element is represented above.

(a) Identify the element.

A radioactive isotope of the element decays with a half-life of 10. minutes.

(b) Calculate the value of the rate constant, k, for the radioactive decay. Include units with your answer.

(c) If 64 atoms of the radioactive isotope are originally present in a sample, what is the expected amount of time that will pass until only one atom of the isotope remains? Show how you arrived at your answer.

a) Flourine

b) $t_{1/2} = 10$ min or 600 sec

$t_{1/2} = \frac{0.693}{k}$ $\quad 600\text{sec} = \frac{0.693}{k}$ $\quad \boxed{k = 1.2 \cdot 10^{-3}}$

c) 64 atoms $\quad t_{1/2} = 10$ min or 600 sec

$\frac{64}{2} = 32$ ~~at 10 min~~

16 at 15 min

8 at 20 min

4 at 25 min

2 at 30 min

$\boxed{35 \text{ minutes}}$

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AP® SAMPLE STUDENT RESPONSES AND SCORING NOTES
2018 AP CHEMISTRY

Question 7

Sample Identifier: 7A
Score: 4

- In part (a) the student correctly identifies the element to earn 1 point.
- In part (b) the student substitutes numbers in the half-life formula and calculates the correct value to earn 1 point. The student includes correct units to earn 1 point.
- In part (c) the student uses a valid method and correctly calculates time to earn 1 point.

Sample Identifier: 7B
Score: 3

- In part (a) the student correctly identifies the element to earn 1 point.
- In part (b) the student substitutes an equivalent time in the half-life formula and calculates a correct rate constant to earn 1 point. The student includes a unit consistent with the value to earn 1 point.
- In part (c) the student uses a valid method but calculates an incorrect time and does not earn the point.

Sample Identifier: 7C
Score: 2

- In part (a) the student correctly identifies the element to earn 1 point.
- In part (b) the student substitutes numbers in the half-life formula and calculates the correct value to earn 1 point. The student includes an incorrect unit and does not earn the unit point.
- In part (c) the student uses an invalid method and calculates an incorrect time and does not earn the point.

Sample Identifier: 7D
Score: 1

- In part (a) the student identifies an incorrect element and does not earn the point.
- In part (b) the student substitutes an equivalent time in the half-life formula and calculates a correct rate constant value to earn 1 point. The student does not include a unit and does not earn the unit point.
- In part (c) the student uses an invalid method and calculates an incorrect time and does not earn the point.

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